White Paper

SCIA Scaffolding

Providing an accurate design and time-saving workflow

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SCIA Scaffolding: Providing an accurate design and time-saving workflow

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1. Introduction

For centuries scaffolding has been used as a means to facilitate the construction process. Towers, bridges, churches, have all been erected using scaffolds [Ref.10].

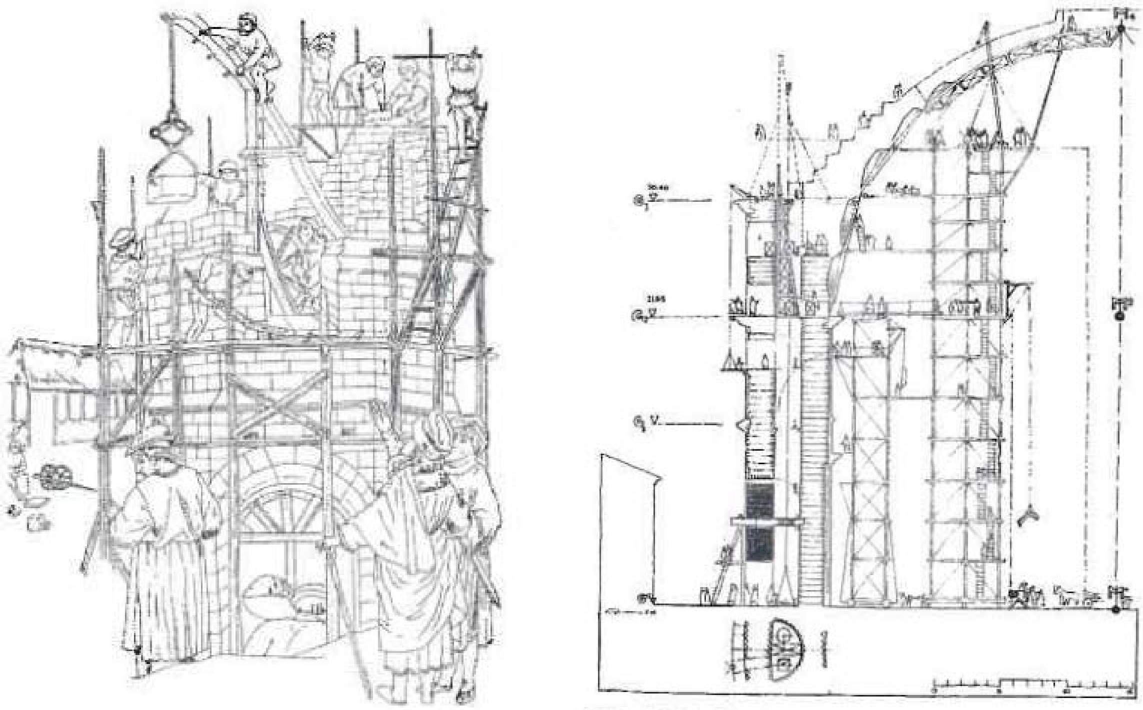

Figure 1: Illustrations of scaffolds used throughout history

In the past, calculation and design was aimed at the structure itself. A scaffold was merely a means to attain the goal. In the present era, the analysis of the scaffold as a 'true' structure has gained a huge importance.

One of the main reasons for this are the numerous accidents that occurred with scaffolding over time which in many cases were caused by faulty design [Ref.13] [Ref.14].

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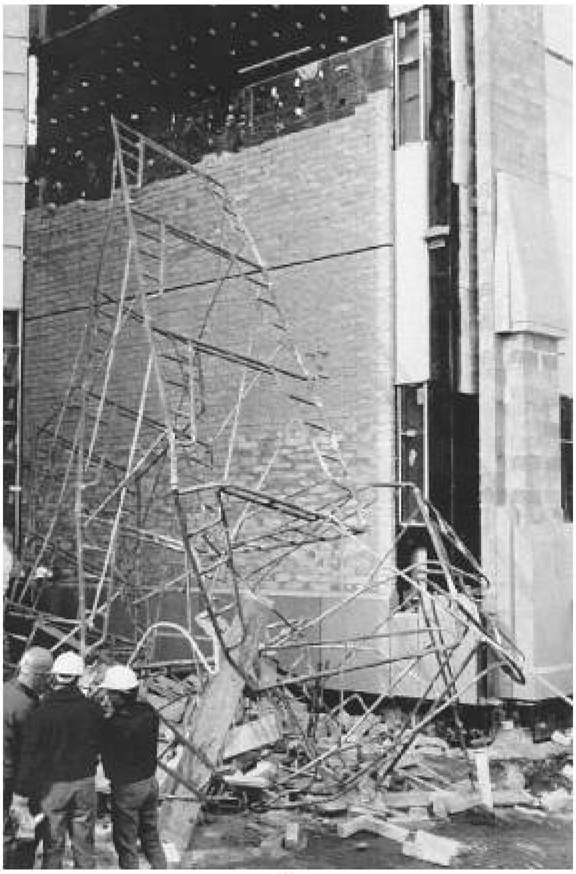

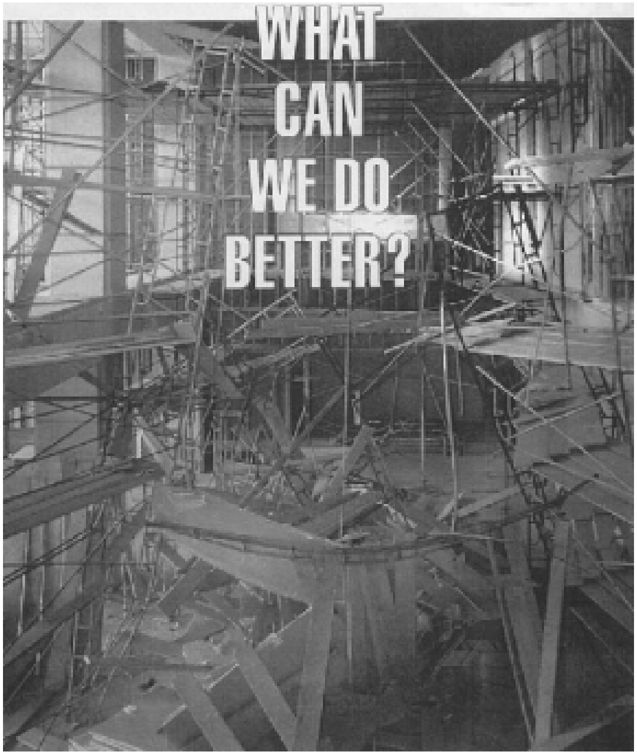

Figure 2: Examples of scaffolding accidents

Recently European standard EN 12811 [Ref.3] has been published which gives guidelines on the safety and design of scaffolding structures. In addition, a specific standard EN 12810 [Ref.1] was published concerning façade scaffolds.

In this paper first of all an overview is given of the method of analysis which is presented in these European standards. In a separate chapter the modelling and analysis of scaffolding structures within Scia Engineer is outlined.

The method of analysis is then illustrated and verified by comparing the results of a Scia Engineer analysis model to an actual laboratory test.

The final part of this paper details the S Scaffolding design methodology which uses a single intelligent model for all phases of the working process. The advantages of this approach compared to the existing workflow are illustrated.

2. Complexity of Scaffolds

In many cases, scaffolds are designed using common linear analysis together with the effective length method. In this case the internal forces are derived from a linear 1st order analysis and the members are designed according to a relevant design code [Ref.11].

It has however been pointed out that this method of design is not reliable in case of scaffolding structures due to the following:

a) Scaffolds contain a high degree of non-linearity.

b) Scaffolds are prone to large deflections.

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The first cause, high degree of non-linearity, is seen directly when examining a scaffolding structure more closely. Every ledger is connected to the standards using couplers. These couplers behave in a non-linear way as illustrated on the following diagram [Ref.12] [Ref.10].

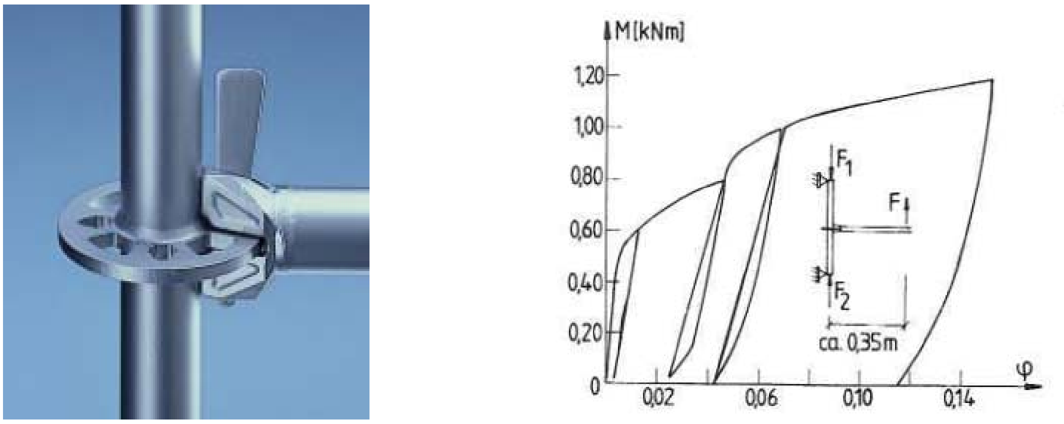

Figure 3: Scaffold coupler with non-linear stiffness diagram

In the same way the base jacks at the bottom of the scaffold behave non-linear and are even subject to friction effects. These non-linear behaviours are found at practically every node of the system.

The second cause, large deformations, implies that 2nd order effects are very important within scaffolding systems. By design, a scaffolding structure is not perfectly straight: the standards are inclined to one another and also the base jacks and base standards have a different inclination [Ref.10].

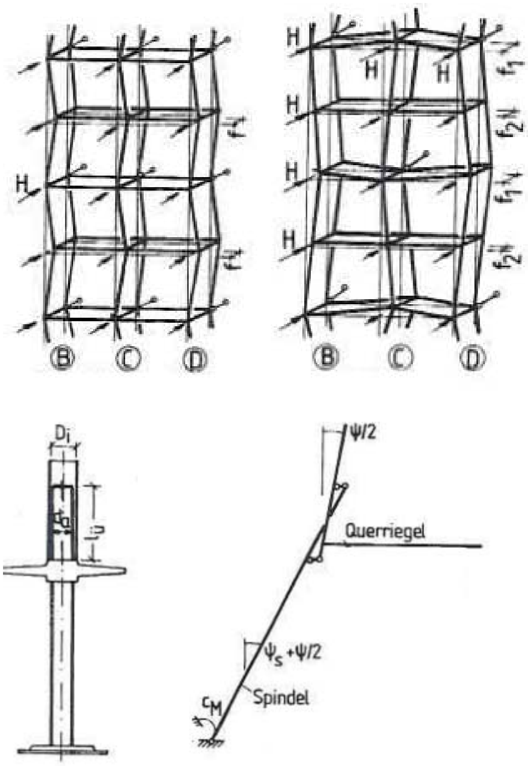

Figure 4: Inclinations of standards and base jacks

As a result of these inclinations, vertical loading on the scaffold inevitably also causes horizontal loading which in turn make the scaffold prone to 2nd order effects.

The above two aspects are in many cases ignored by engineers which can lead to unsafe designs [Ref.14].

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The recent European standards take these complex behaviours into account by first of all specifying guidelines and test methods to determine the non-linear structural characteristics of modular nodes (couplers). These methods are given in EN 12811-3 [Ref.5].

In most cases, this information is already available; all common manufacturers have detailed test reports which have been used to determine the stiffness and resistance values of their specific systems.
The standards explicitly state that this realistic load-deformation behaviour of the connecting devices needs to be incorporated in the analysis model.

Second, the codes specify the use of a 2nd order analysis as the preferred path of analysis (EN 12810-2 [Ref.2]). In this case, the equilibrium of the displaced system is taken into account directly.

The different stages of the structural design using the preferred path of analysis are illustrated on the following flowchart:

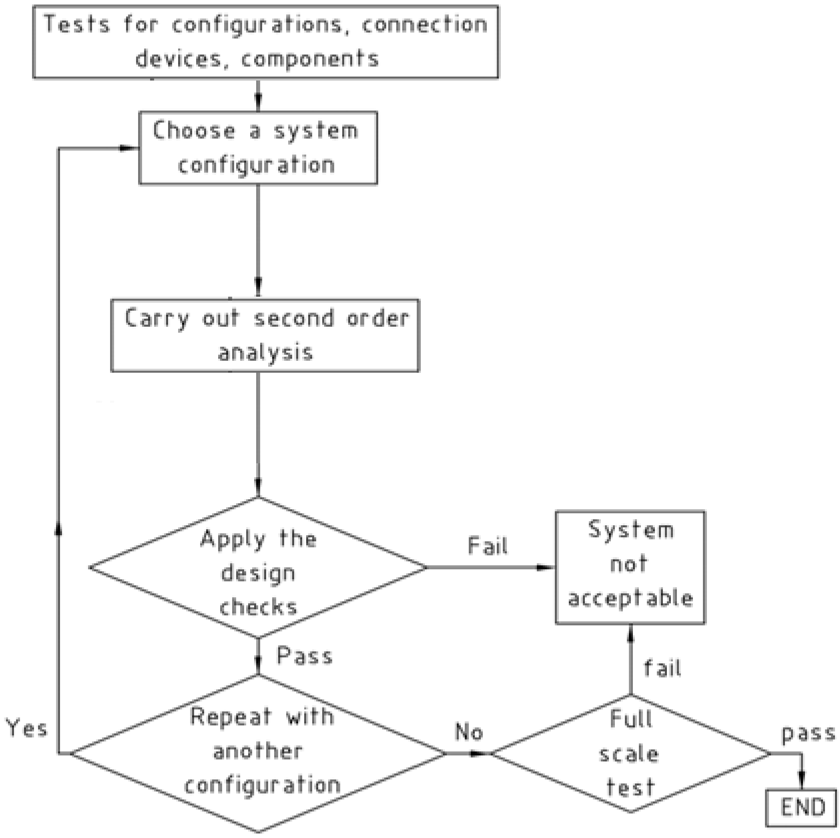

Figure 5: Flowchart of the EN 12810-2 preferred path using 2nd Order analysis

Of special interest in this diagram is the final step: 'Full scale test'. The code specifies that such a test should be carried out on a representative system configuration to verify the correctness of the analysis model. In the next chapter of this paper this is further detailed.

The main advantage of using a 2ndorder analysis which includes both global (P-Δ) and local (P-δ) effects is the fact that a section capacity check is adequate to assess the components.
For this reason, EN 12811-1 only specifies a section check interaction formula.

Alternatively the codes also allow the use of a first order analysis with amplification factors. This method is however subject to several limitations and is not applicable to any type of scaffolding system.
Especially in the current age of analysis software for structural design there is no reason to apply the alternative method instead of the more general and always accurate one.

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3. Scaffolding analysis within SCIA Engineer

In this chapter, the modelling and design of scaffolding structures within SCIA Engineer are detailed.
Virtually any type of scaffold can be analysed using SCIA Engineer: from modular systems to frame systems or even tube & coupler scaffolds.

Through different paragraphs the chapter highlights key steps in the creation of the SCIA Engineer model.

Scaffolding Template

When starting a new project, it is possible to start from scratch or to use a predefined template.

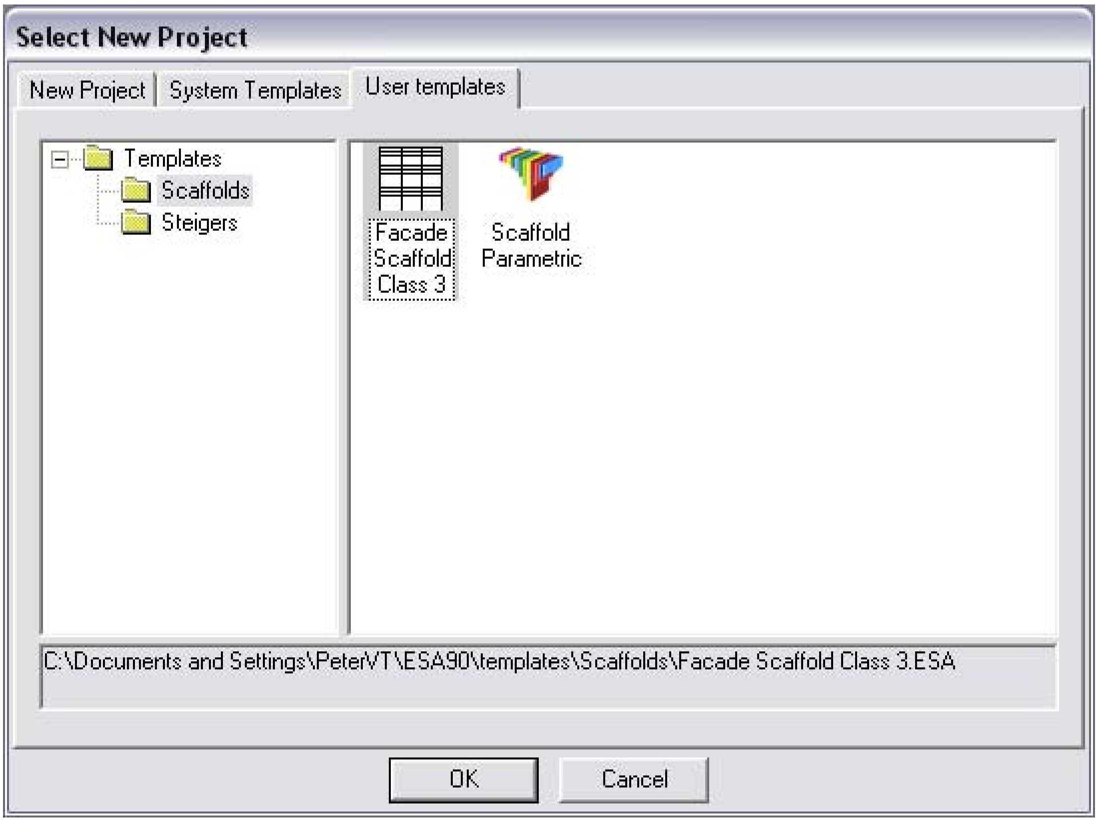

Figure 6: Scaffolding template within SCIAa Engineer

The picture shows a template for a typical Class 3 scaffold according to EN 12811-1. These scaffolds are designed for a working load of 200 kg/m².

The advantage of using a template is that all common data is already filled in (i.e. materials, cross-sections, stiffnesses, combinations ...) which provides a very quick and efficient input.

The following picture illustrates this concept.

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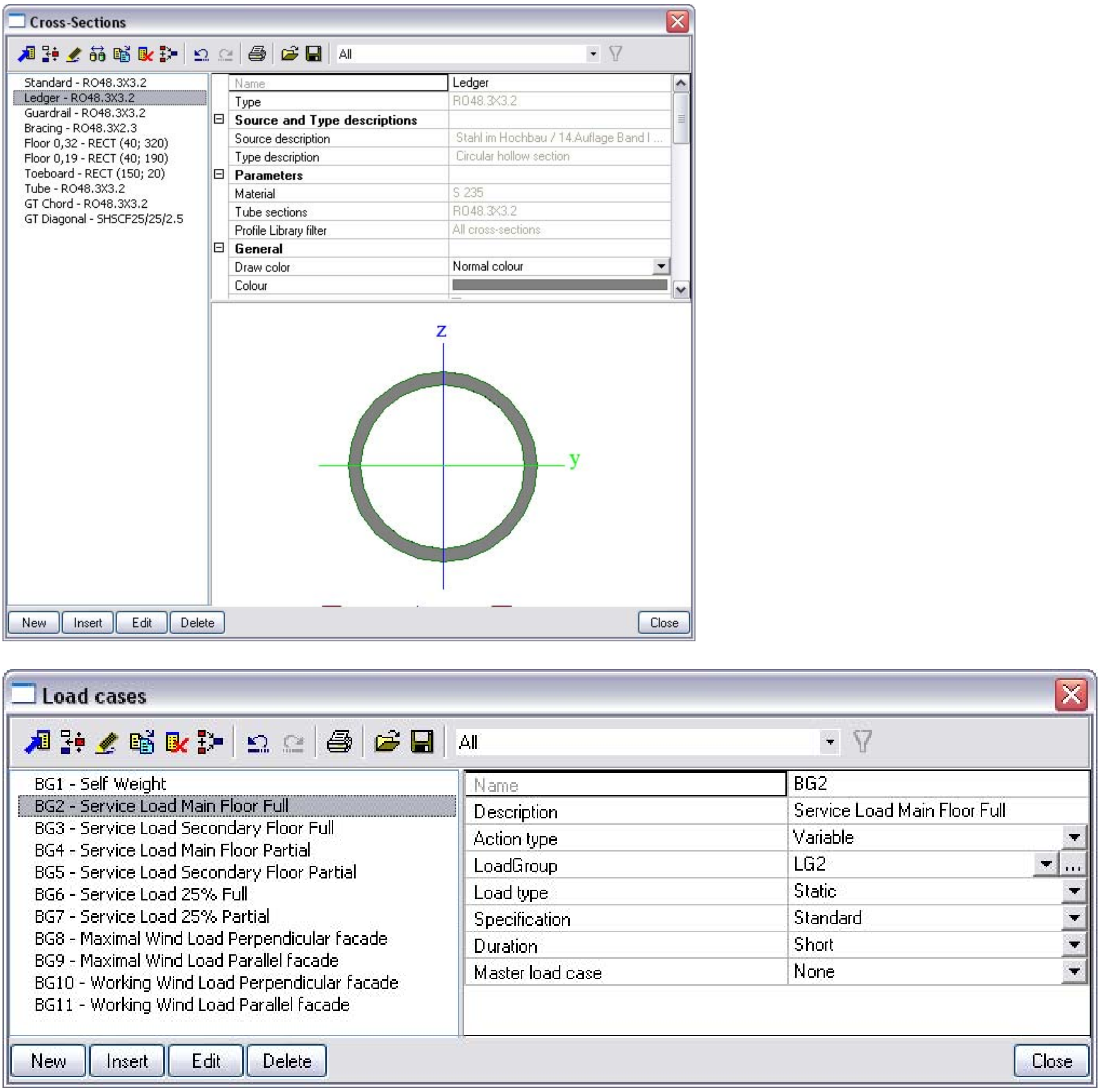

Figure 7: Predefined cross-sections and load cases within a scaffolding template

In addition to this data, the template can also contain part of the scaffold geometry. By adding parameters to such a template, a parameterized scaffold is created which allows for example to quickly define the base of a scaffold.

The following picture shows a parameterized template of a typical façade scaffold. The lengths of each span can be modified to suit the length and geometry of the façade. In addition, should changes be required to the model later on, only these parameters need to be altered and automatically the full scaffold adapts.

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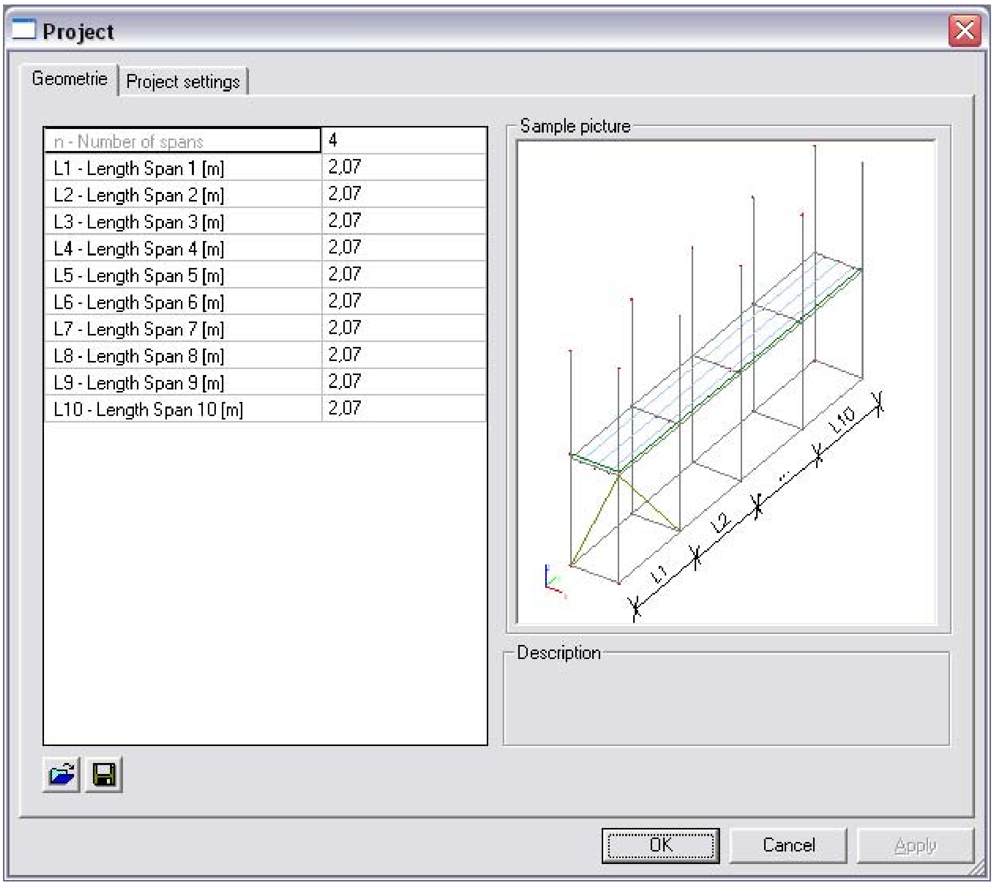

Figure 8: Parametric template for a façade scaffold

Modelling Scaffolds

SCIA Engineer provides a variety of options to create the analysis and structural model. Using typical input options (copy, move, mirror ...) a scaffold can be modelled with ease.

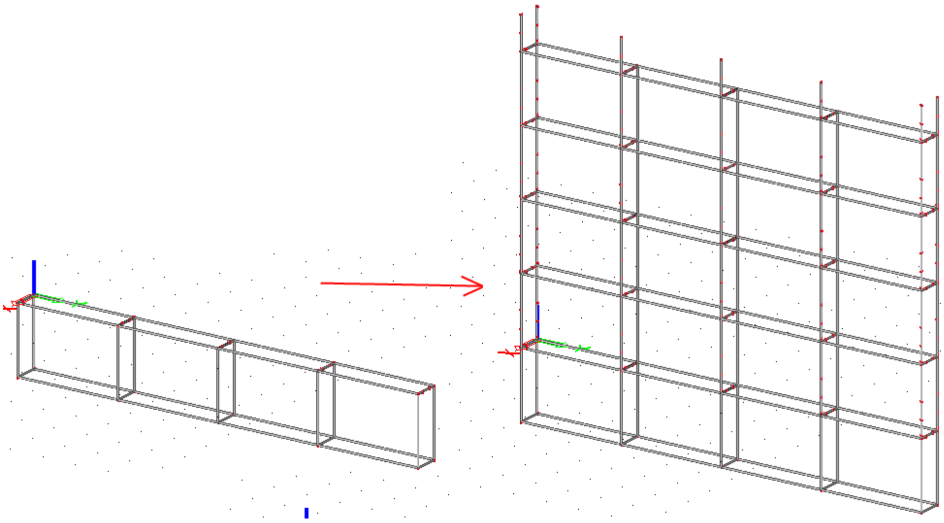

Figure 9: Illustration of default copy function

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In case a 2D or 3D AutoCAD file of the scaffold is available, this is imported directly as an analysis model.

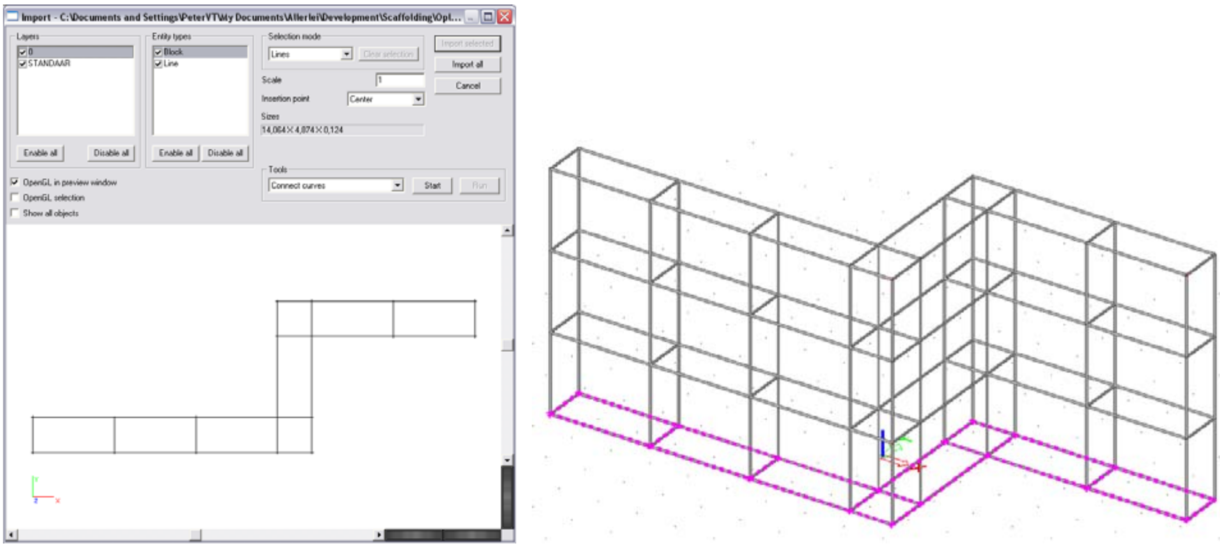

Figure 10: AutoCAD drawing imported as analysis model

Even architectural models can be imported which allows the user to model the scaffold near the existing building for example. The following figure shows this principle for a scaffolding structure within a tank.

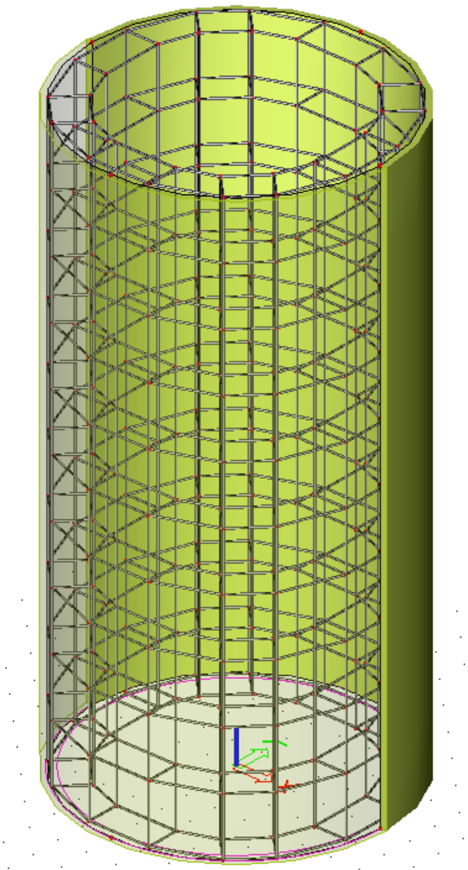

Figure 11: Analysis model of a scaffold completed with an architectural model of a tank

The tank itself was set as 'structural model only' so it does not influence the analysis. Half of the tank was set transparent in order to see the scaffolding structure 'through' the tank wall.

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In addition, SCIA Engineer allows the use of User Blocks i.e. standardised blocks of geometry defined by the user. A typical application of these blocks is a bridging ledger: the lattice girders are defined as blocks in order to easily import them into any scaffold project.

Additional elements like toeboards, guard rails, floorboards ... are all added to the analysis model. In addition to the extra stiffness they provide, the advantage of modelling them is that the self weight is accurately calculated.

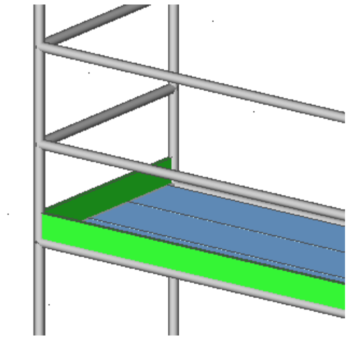

Figure 12: Analysis model including toeboards, guard rails and floorboards

To finalize this paragraph on modelling, the following picture show a SCIA Engineer model of a scaffold around the deck of a bascule bridge [Ref.19]:

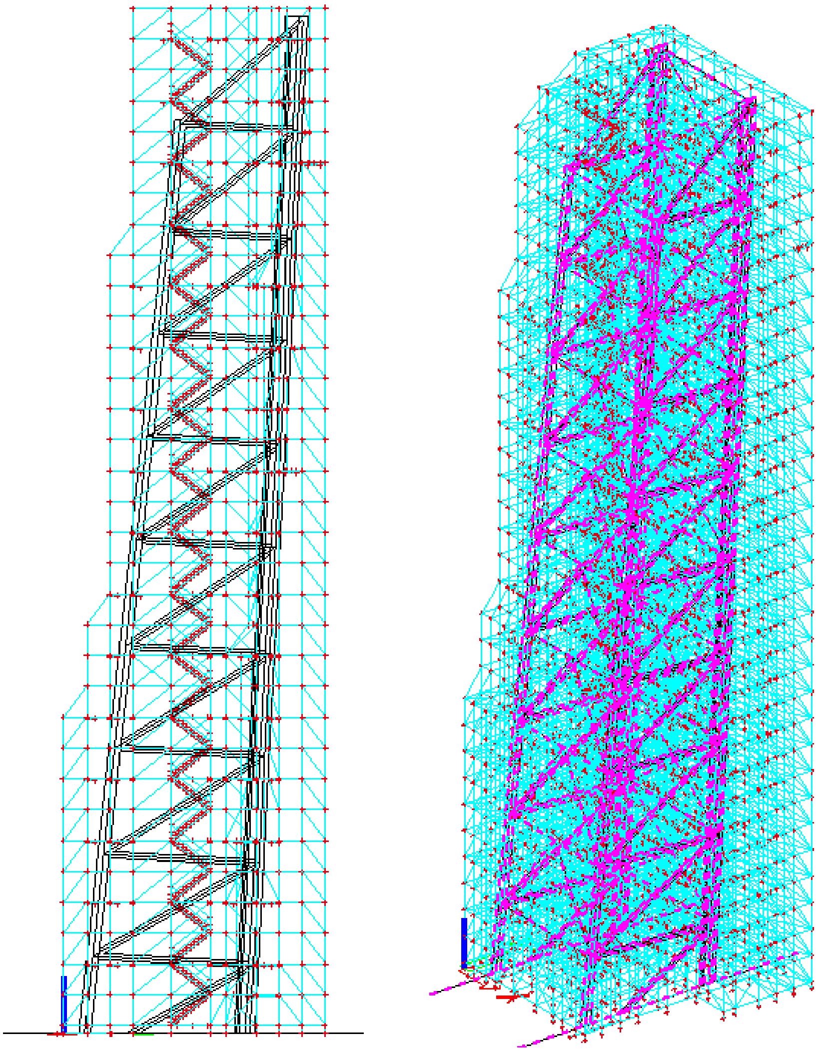

Figure 13: Analysis model of scaffold around a bascule bridge

The advantage of including the bridge deck itself in the structural model is that it allows the user to visually perform a 'clash check' to see if there are no conflicts between the scaffolding structure and the deck.

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Coupler Stiffnesses

As indicated in the previous chapter, the new design standards [Ref.2] explicitly state that the non-linear structural characteristics of modular nodes have to be accounted for in the analysis model.

Within SCIA Engineer, an extensive Library is available which contains the different coupler types given in Annex C of EN 12811-1.

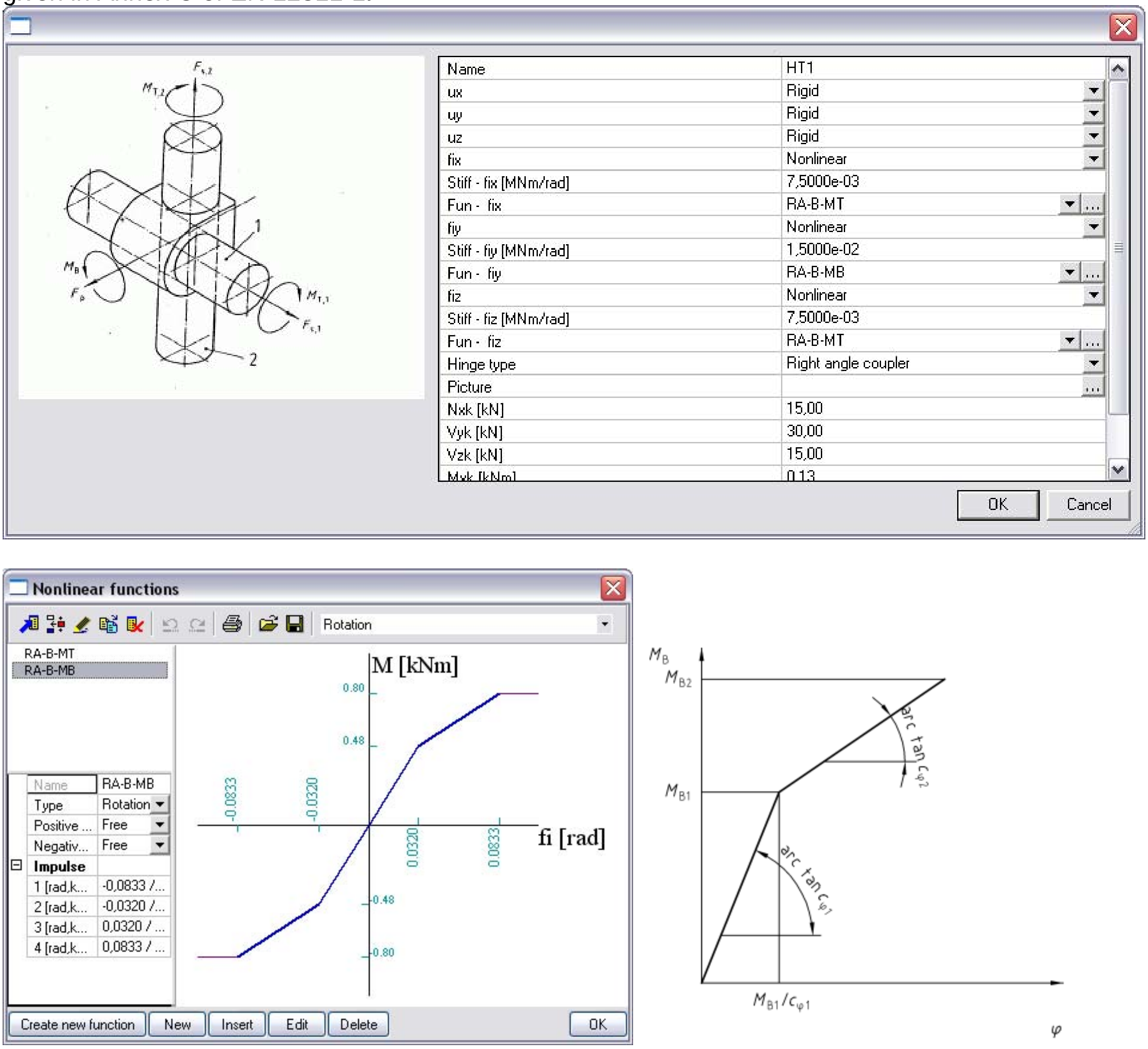

Figure 14: Coupler Library including non-linear spring functions

The user can easily select any of the predefined coupler types and assign these couplers as non-linear springs to any member (ledger, standard, diagonal ...).

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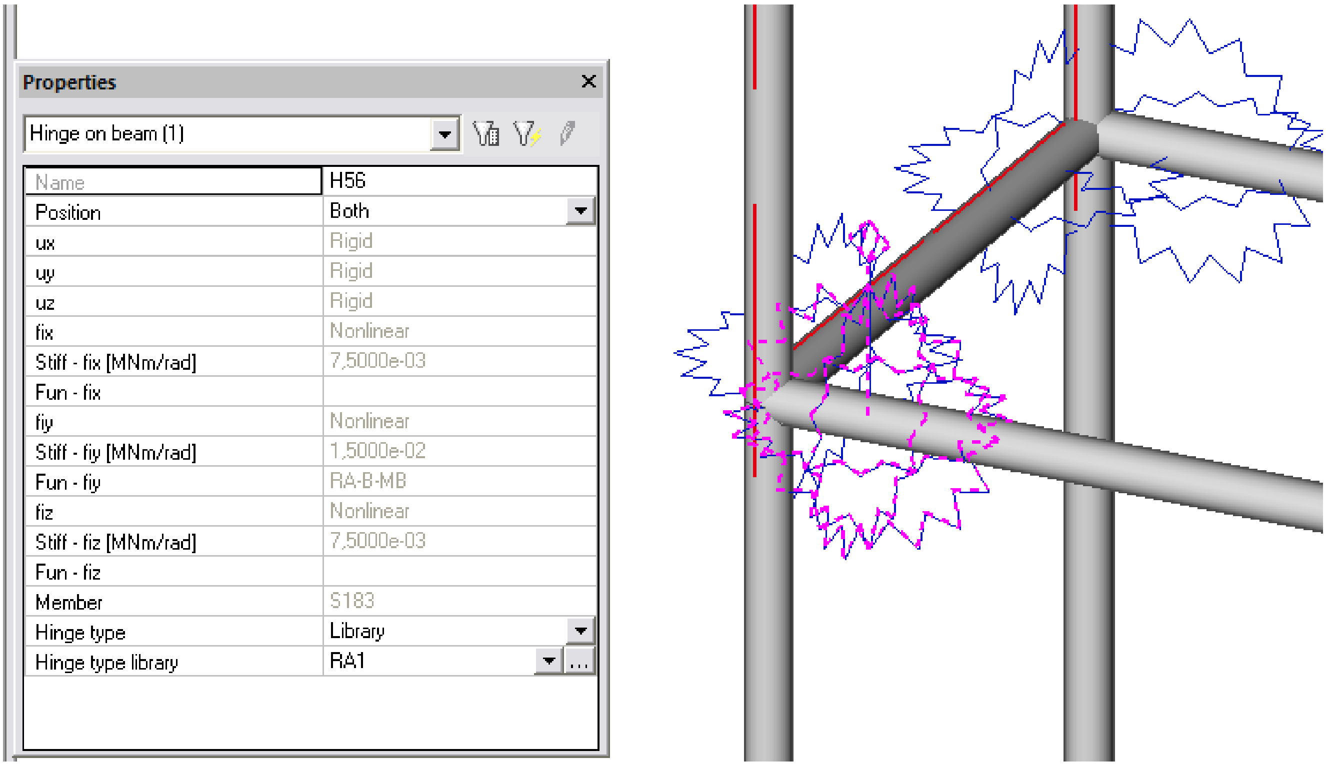

Figure 15: Assigning couplers to members

In addition to the stiffnesses, the Library also contains the resistance values of these couplers. These are used after the analysis to execute a coupler check.

Another advantage of this Library is that it concerns an open system: the user is free to add any type of scaffold coupler including stiffness and resistance values. In this way, it is possible to add manufacturer specific coupler types to the Library.

Couplers & Scaffolding types

The previous paragraphs specified how the modelling of scaffolds and coupler is handled in SCIA Engineer. In this paragraph, this is illustrated for different scaffolding types.

a) “Tube & Coupler”

Tube & coupler scaffolds are so-called because they consist of tubes connected by couplers. Their main advantage is their versatility: for virtually any situation a scaffold can be made using tubes & couplers.

Figure 16: Typical connection point in a tube & coupler scaffold

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Within SCIA Engineer this is modeled using the coupler types given in Annex C of EN 12811-1. As specified, in case different coupler types are applied, the user can freely add them into the library.

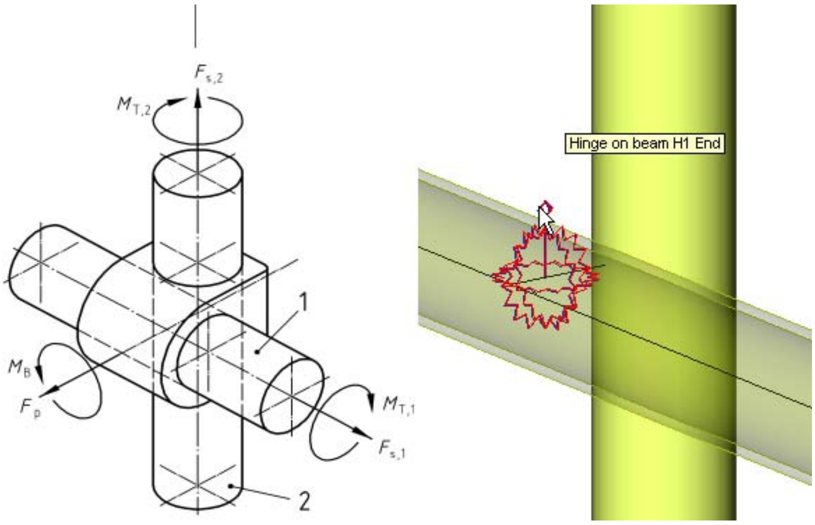

Figure 17: Example of a tube & coupler connection point in SCIA Engineer

b) “Modular systems”

Modular systems are defined as systems in which the transoms and standards are separate components in which the standards provide facilities at predefined (modular) intervals for the connection of the other scaffold components.
One of the main advantages is that they allow a shortened erection time of the scaffold due to the modular approach.

Figure 18: Typical connection point in a modular system scaffold

Within SCIA Engineer this is modelled using the coupler characteristics of the manufacturer.

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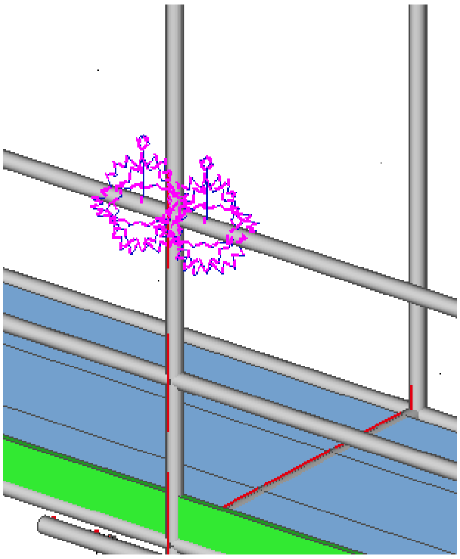

Figure 19: Example of modular system connection point in SCIA Engineer

c) "Frame systems"

A special type of modular systems is the so-called frame system. In a frame system standards and transoms are already welded together as fixed frames. This type of scaffold is typically found in rental stores and used for small paint jobs, construction works etc.

Figure 20: Example of scaffolding frame [Ref.21]

Within SCIA Engineer this is modelled using the stiffness characteristics of the manufacturer.

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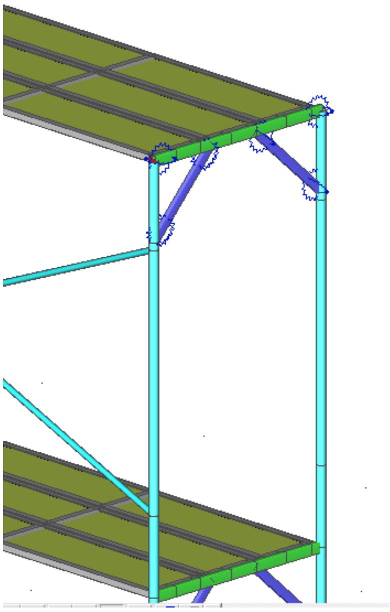

Figure 21: Example of frame system scaffold in SCIA Engineer

All the elements which are part of the frame i.e. standards, transoms, diagonal elements, springs ... can be saved together as one User Block. This ‘frame’ User Block can then be easily inserted into new projects.

Diagonals

Diagonal members are typically attached with an eccentricity due to the geometry of the attachment between the standards and the diagonals [Ref.10].

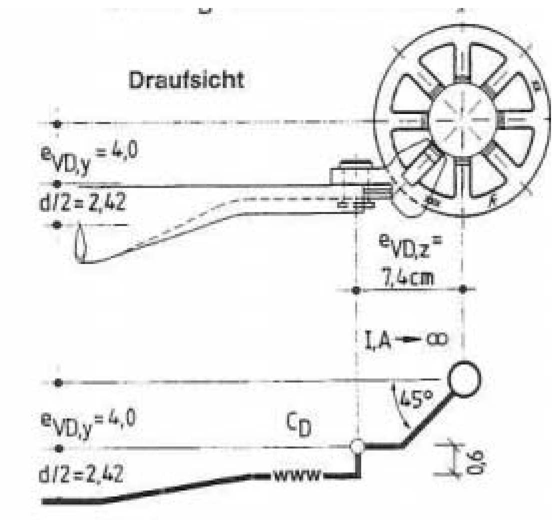

Figure 22: Eccentricity of diagonal members

For the analysis, this eccentricity can have an important influence on the standards. After all, the eccentric normal force in the diagonals causes torsion in the standards.
The torsion in itself will only have a minor value, but when it is combined with the other internal forces within the standard it can lead to an augmented utilization factor.

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Within SCIA Engineer this is accounted for by applying an eccentricity to the diagonal members as shown on the following picture.

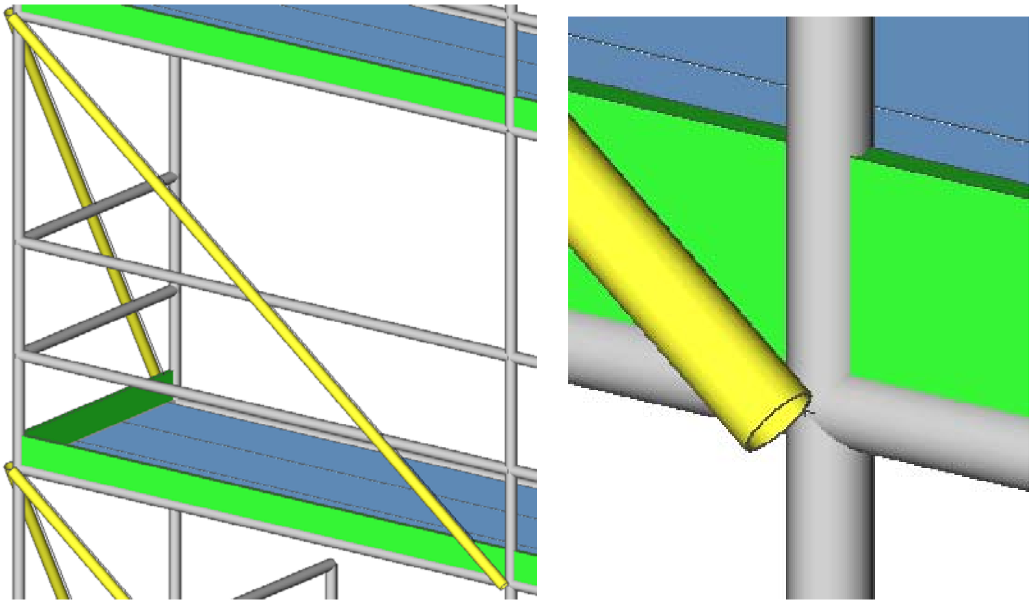

Figure 23: Eccentricity of diagonals in the analysis model

In contrast to a typical steel structure, diagonals used in scaffoldings are typically designed for both tension and compression.

In addition to an eccentricity, a special behaviour of diagonals in modular systems is that they mostly have a small gap along their length, caused by a slight margin between the pen and hole which form the hinged connection [Ref.22].

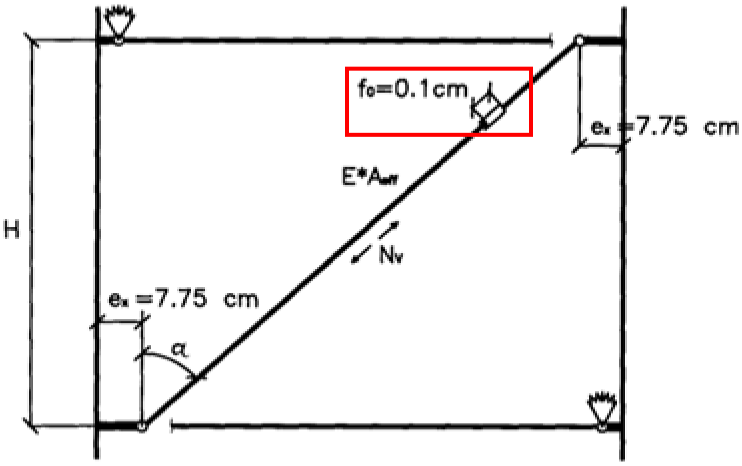

Figure 24: Illustration of 1mm gap in diagonal element

Especially for big scaffolds used as framework structures it is important to take this behaviour into account since it has a significant influence on the overall buckling behaviour of the structure.

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Within SCIA Engineer this behaviour is accounted for using gap elements:

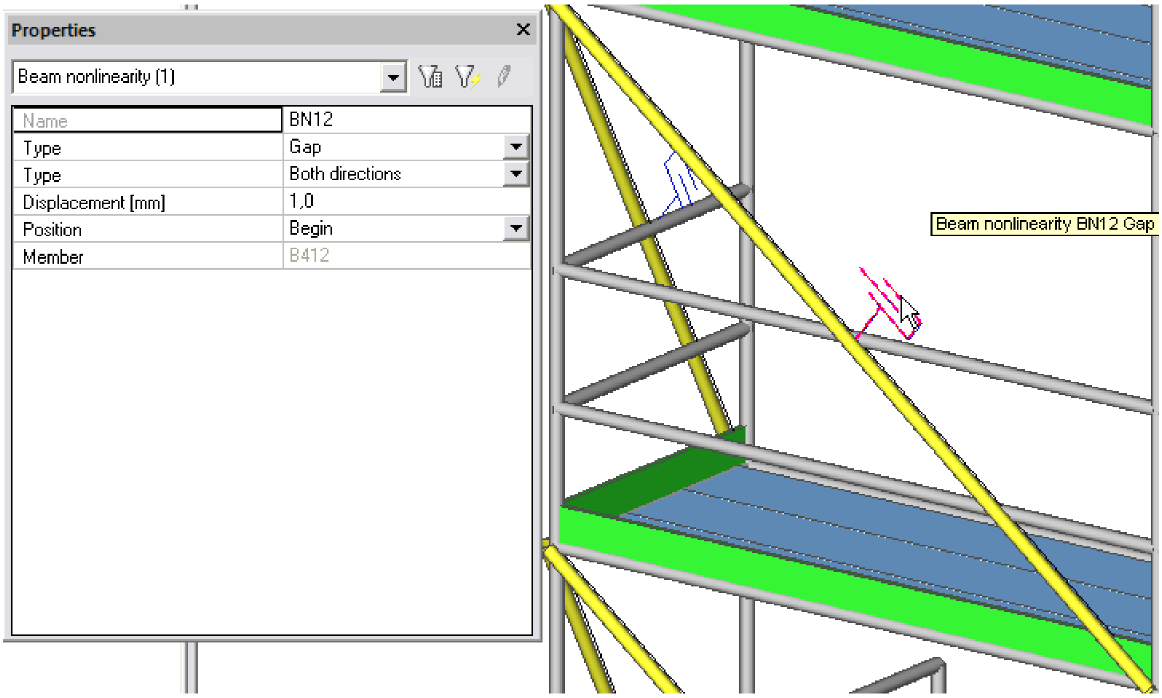

Figure 25: Definition of gap elements on diagonals

As an alternative, in case specific test results for the diagonals of modular systems are available, the stiffness derived from the tests is accounted for in the SCIA Engineer model as a translation spring:

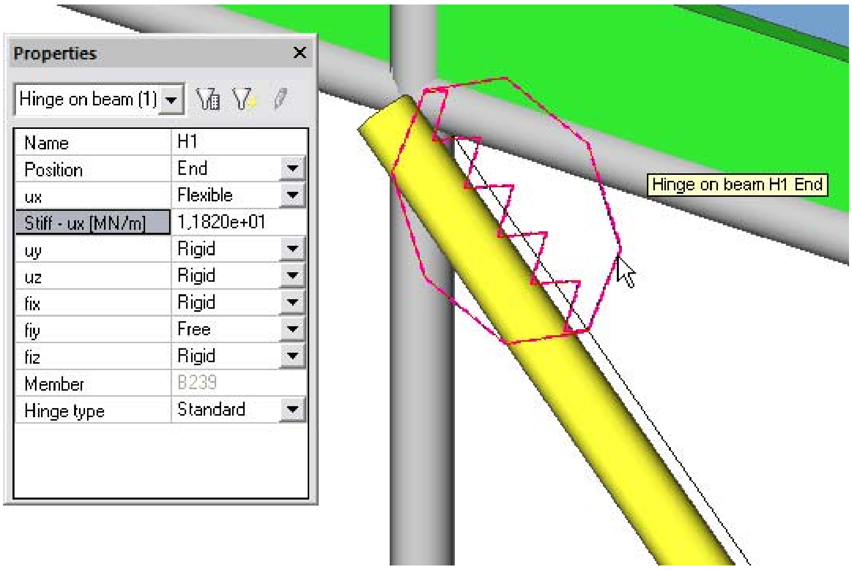

Figure 26: Translation spring for longitudinal stiffness of diagonals

As specified before, these stiffnesses can be saved into a database to easily retrieve them in future projects.

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Floorboards

Scaffolding structures typically have two types of floor systems: metal boards or wooden planks.

The metal floor boards are accounted for in the stiffness of the analysis model. In this case it is however important to model a correct rotational spring stiffness for the connection between the floor board and the transom. After all, the floorboard can first have some rotation in the plane of the floor before it actually makes contact with the transom in order to transfer loading.
Within SCIA Engineer this is again accounted for using the non-linear functions introduced for the coupler stiffnesses.

In case wooden planks are used however, the stiffness of the planks cannot be accounted for since in most cases the planks are put loose on the transoms. In this case, the planks are modelled as an additional loading.

Base jacks

The base jacks at the bottom of the scaffold have a very specific behaviour.

In most cases, the base jacks are not fixed to the ground. As a result, in case of uplift forces the base jack can be lifted from the ground.
In addition, the horizontal resistance which the base jack provides is purely dependent on friction i.e. the higher the vertical loading, the more horizontal loading can be withstood before the base jack starts sliding away.

Within SCIA Engineer this advanced behaviour is modelled using friction supports.

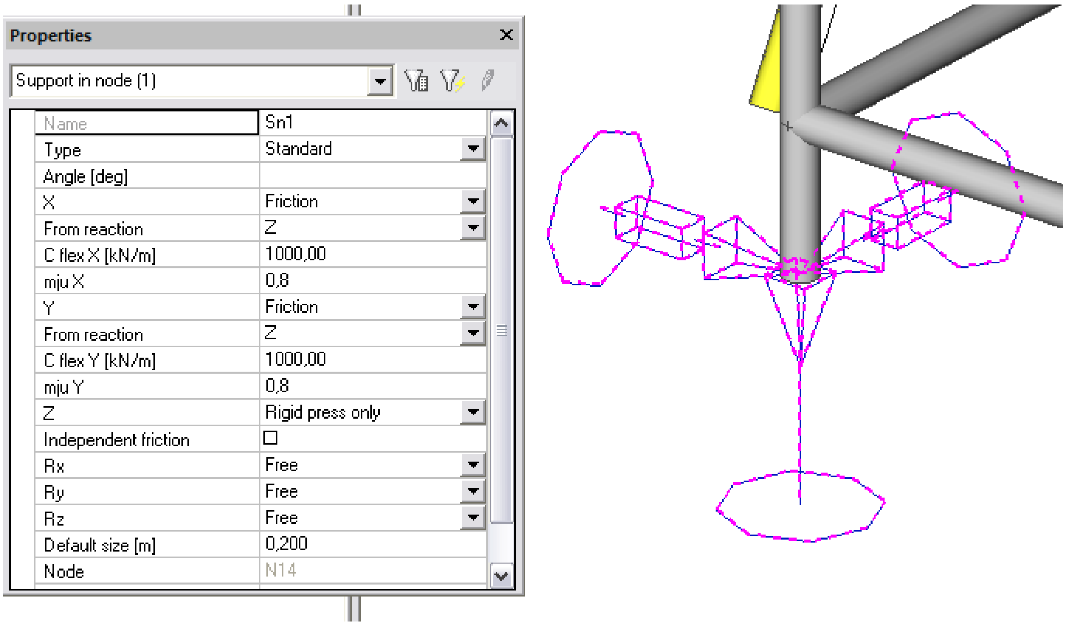

Figure 27: Definition of base jacks as friction supports

The vertical direction is set to be ‘Pressure only’ and the horizontal resistances are set to be friction dependent on the vertical direction. For base jacks resting on wooden load spreading planks, the friction factor typically ranges between 0.5 and 1.2.

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Especially in case of clad façade scaffolds with low vertical loading which are subject to extreme wind loading the base jacks can start to slide as shown on the following picture:

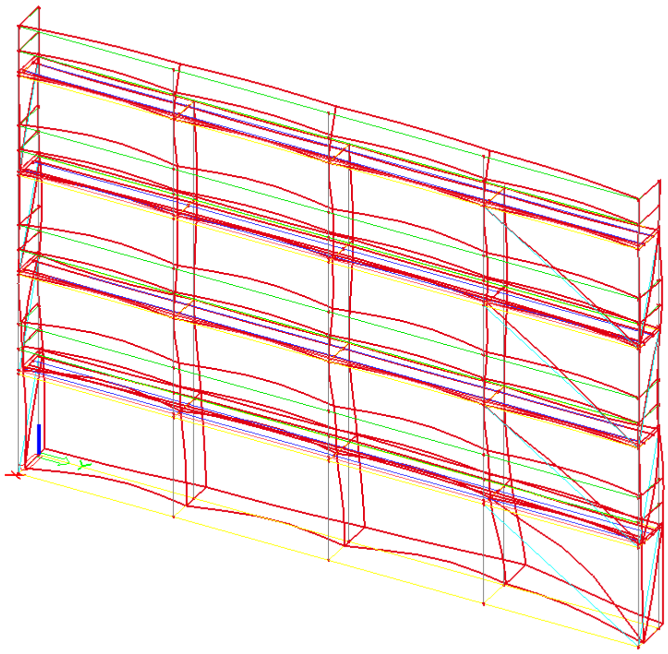

Figure 28: Sliding of base jacks

Using SCIA Engineer this behaviour is accounted for in the analysis in order to provide the designer with a clear indication that additional ballast is required.
EN 12811-1 [Ref.3] indicates that working scaffolds should always be verified for local sliding.

Anchorages

EN 12810-2 [Ref.2] specifies that the connection between the ties and the façade shall be modelled in such a way that the ties are free to rotate about axes in the plane of the façade and shall not be assumed to transmit vertical forces.

Within the SCIA Engineer model, the anchorages are thus set to transfer horizontal loads to the façade.

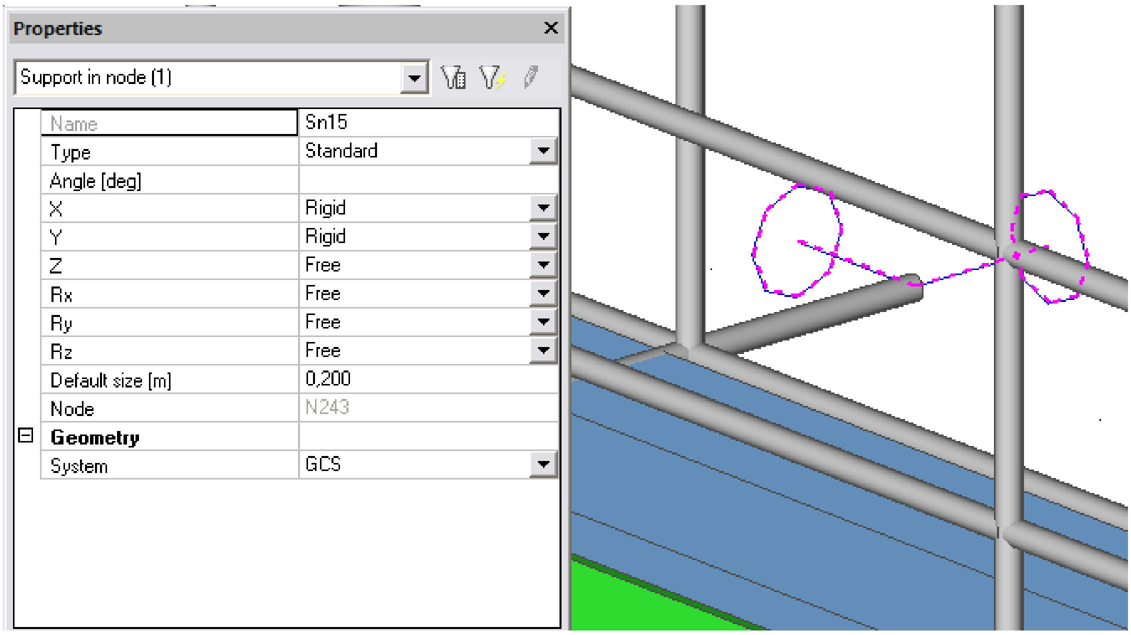

Figure 29: Anchorages in the analysis model

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Using ‘Pressure only’ supports, instead of anchorages so called abutments are modelled. Such abutments are typically used in case of working scaffolds around the towers of churches. In such cases the scaffold may ‘push’ against the roof of the church but not ‘pull’ on the antique structure.

Loading

According to EN 12811-1 a scaffold should be designed for two specific conditions:

- In Service: Characterized by a high working load and only a minor ‘working’ wind loading.

- Out of Service: Characterized by an extreme wind loading and a small percentage of the working load, signifying material left on the scaffold.

Using a template as indicated above, all required load cases and combinations are already predefined which saves time during the input process.

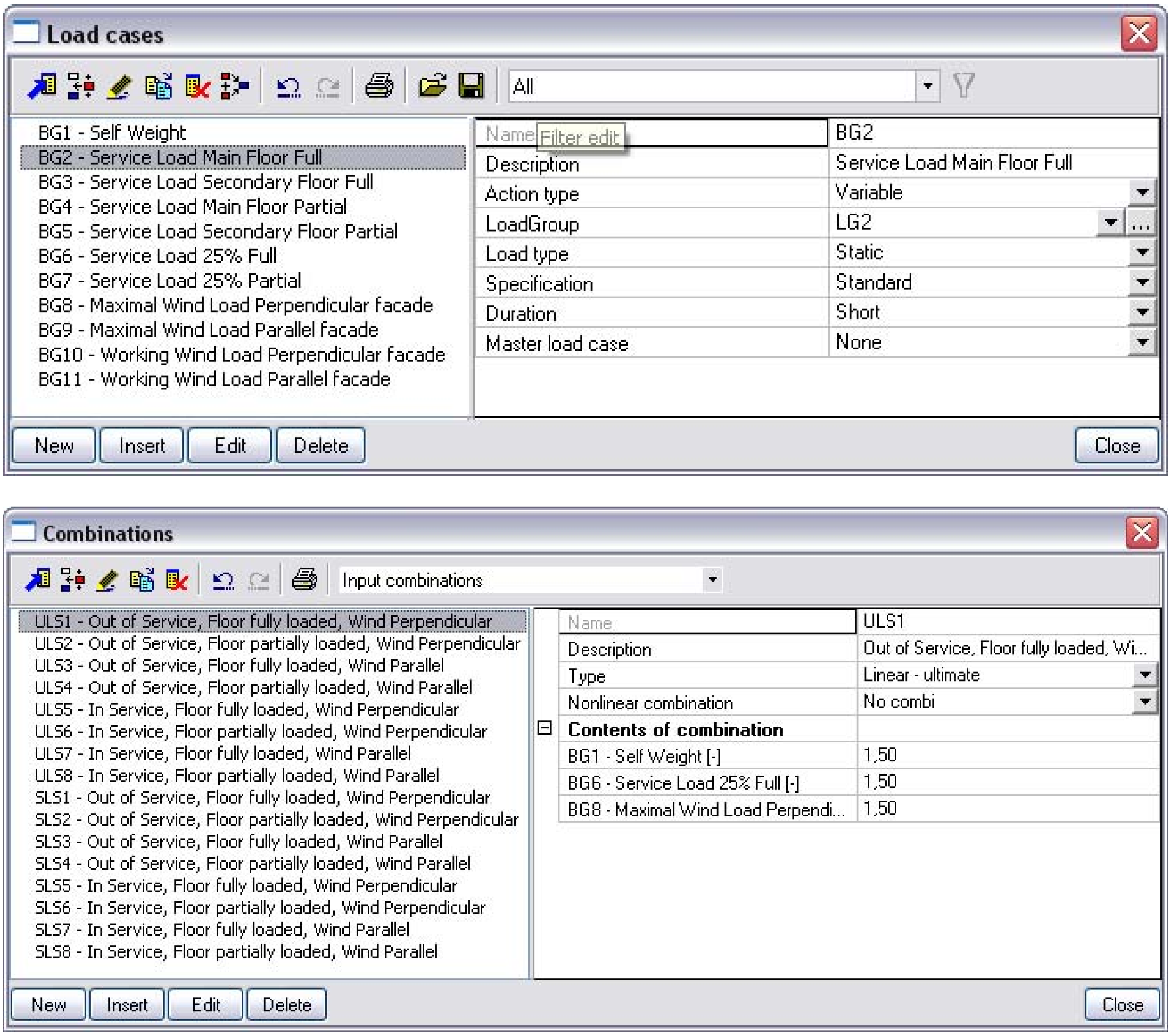

Figure 30: Predefined load cases and combinations within a scaffolding template

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In case the floor boards are modelled as 1D members, the service load is inputted as a line load as shown on the following picture:

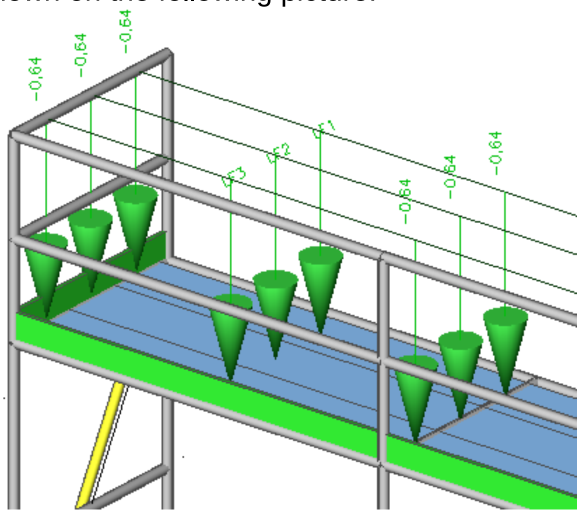

Figure 31: Working load defined on floorboards

In exactly the same way 2D loads are used for floor boards modelled as 2D elements.

Instead of a tedious input of wind loading, Scia Engineer provides an easy and straightforward mechanism called the 'Plane Load Generator'. This generator allows the user to define the plane on which the loading acts after which SCIA Engineer automatically distributes the loading on all members within the plane.

This principle is illustrated on the following pictures using perpendicular wind on a façade scaffold:

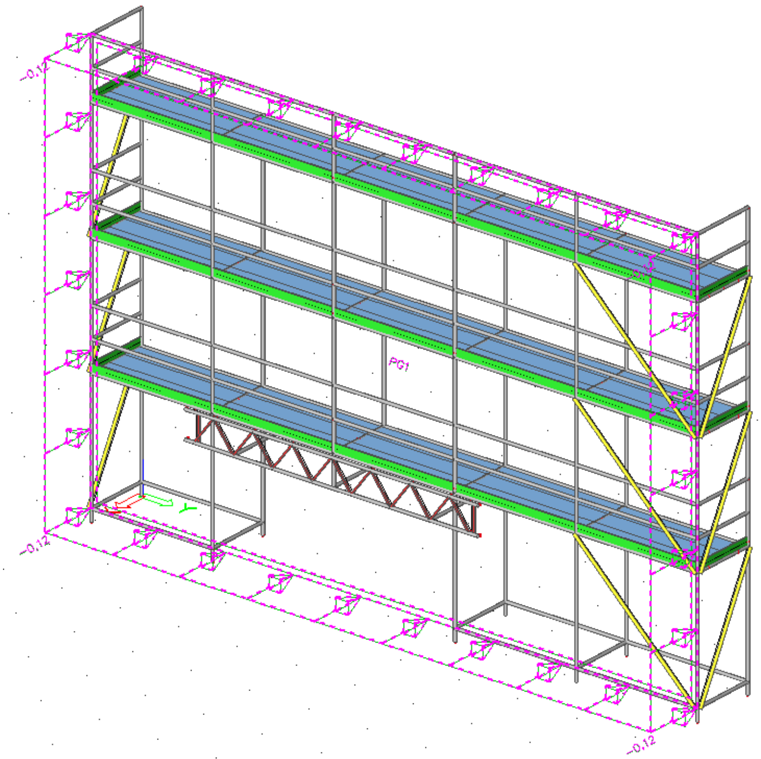

Figure 32: Definition of the plane load geometry on a façade scaffold

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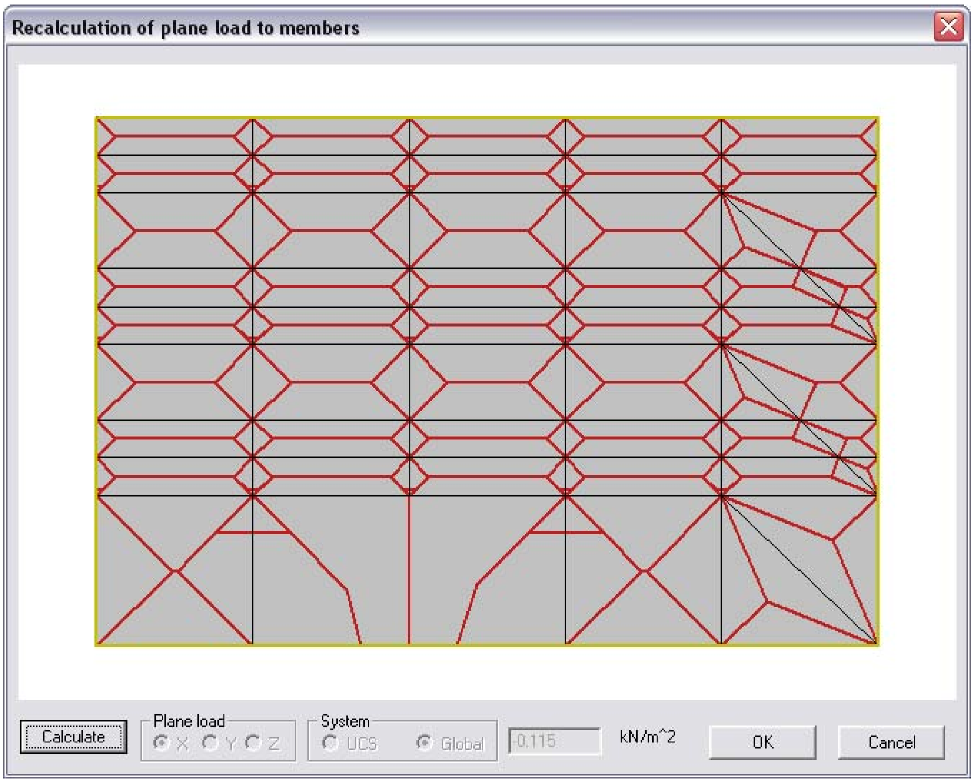

Figure 33: Automatic distribution of the loading

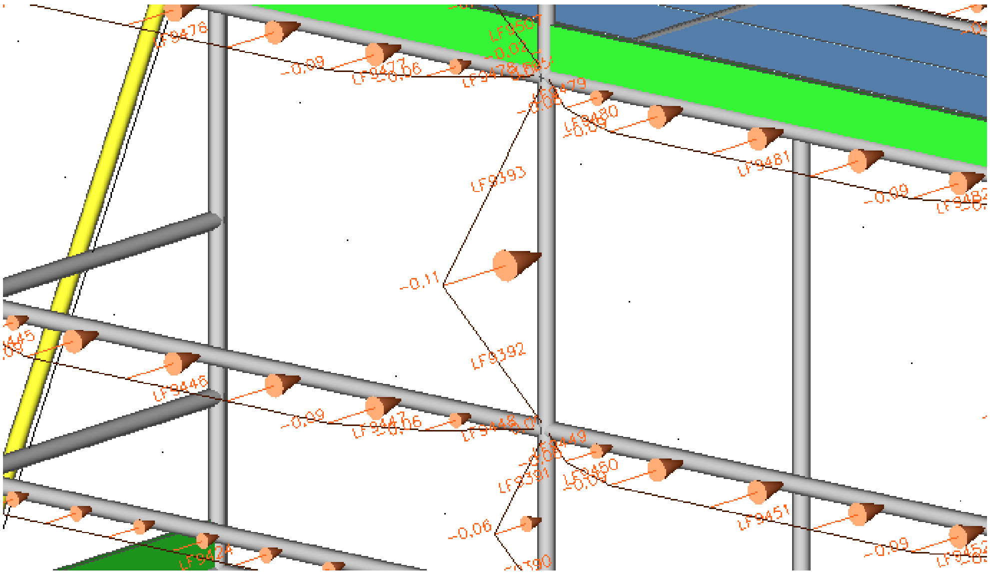

Figure 34: Generated loading on the scaffold

Using this approach, even the wind loading for complex scaffolds can easily be defined.

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Analysis

After defining the geometry and loading, a 2nd order analysis is executed. As specified in the introduction, this analysis should include both global (P-Δ) and local (P-δ) effects.

The main aim of these imperfections is to 'try' to get an initial shape of the scaffold which matches the buckling shape [Ref.16]. EN 1993-1-1 [Ref.17] however specifies that, instead of applying global and local imperfections, the real buckling shape itself can be applied as a unique imperfection.
It is clear that this is the most correct solution since, instead of trying to approximate the shape; the actual shape itself is used.

Within SCIA Engineer this exact method is used through a stability analysis: an eigenvalue analysis determines the buckling shapes of the scaffold which in turn are used as imperfections for the 2nd order analysis.

The following picture shows a typical buckling shape of a façade scaffold with a bridging ledger.

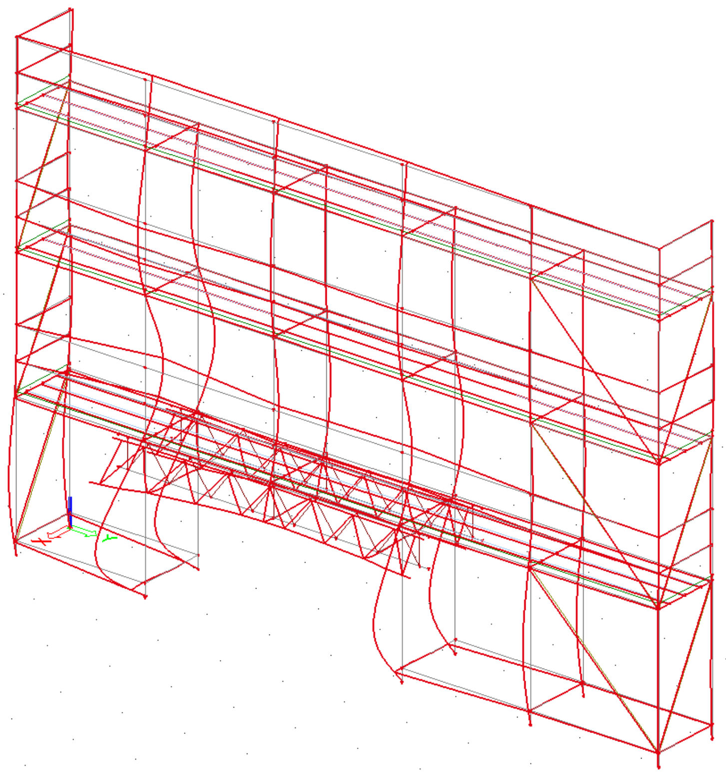

Figure 35: Buckling shape of a façade scaffold with a bridging ledger

Since the analysis includes all required effects, the component stability is already accounted for and does not have to be verified using checks. As a result, only a capacity check has to be executed on the scaffold members, which will be illustrated further on.

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Ultimate Limit State

In ultimate limit state, the scaffold members can be checked according to the capacity check defined in EN 12811-1 [Ref.3]

Scaffolding check

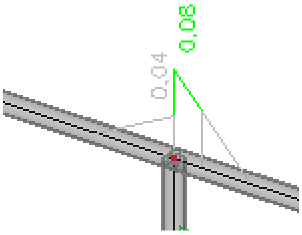
according to EN12811-1:2003, art 10.3.3.2 and equation 9

Table of values		
Npl.d	106.46	kN
Vpl.d	39.13	kN
Mpl.d	1.41	kNm
unity check	8.96	

Figure 36: Output of EN 12811-1 scaffolding check

This check is based on the DIN 4420 code [Ref.18] which contains a more thorough interaction check. Within Scia Engineer, both methods have been implemented.

In addition to the check of the scaffold members, SCIA Engineer also performs a coupler check as defined in EN 12811-1.



Scaffolding - coupler check

Nonlinear calculation, Extreme : Cross-section
Selection : All
Class : All ULS NL
Verification of coupler

Name	Coupler type	Member position	Case	Unity Check - Max [-]	Unity Check - Fx [-]	Unity Check - Fy [-]	Unity Check - Fz [-]	Unity Check - Mx [-]	Unity Check -My [-]	Unity Check -Mz [-]	Unity Check - Interaction [-]
RA	Right angled	B172-Both(end)	All ULS NL	0,27	0,02	0,00	0,27	0,01	0,18	0,00	0,22
RA	Right angled	B95-Both(start)	All ULS NL	0,09	0,01	0,00	0,00	0,00	0,01	0,09	0,01
SW	Swivel	B238-Both(start)	All ULS NL	0,38	0,38						

Figure 37: Output of EN 12811-1 coupler check

In this coupler check, the resistances defined in the coupler library are used.

Beside the specific scaffolding checks, for other member types (for example I-sections used in fork supports of framework structures) a full design according to EN 1993-1-1 [Ref.17] is executed.

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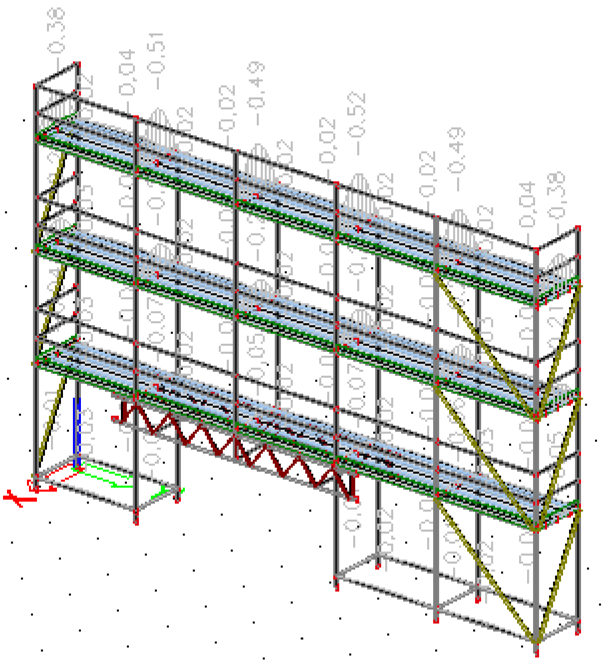
Serviceability Limit State

In addition to the ULS verification, SCIA Engineer allows the user to evaluate the deformations of the scaffold and even perform a check on the relative deformations.



Relative deformation

Linear calculation, Extreme : Global, System : Principal
Selection : All
Class : All SLS
Cross-section : Ledger - RO48.3X3.2

Case - combination	Member	dx [m]	uy [mm]	Rel uy [1/xx]	Check uy [-]	uz [mm]	Rel uz [1/xx]	Check uz [-]
SLS4/1	B29	1,035	**-0,7**	**1/2894**	**0,07**	-0,3	1/7351	0,03
SLS1/2	B29	1,035	**0,7**	**1/2991**	**0,07**	-0,2	1/10000	0,02
SLS5/3	B178	0,545	0,0	0	0,00	**-2,8**	**1/383**	**0,52**
SLS1/2	B171	0,414	0,1	1/10000	0,01	**0,0**	**1/10000**	**0,00**

Figure 38: Output of relative deformation check for ledgers

This is of particular interest to the ledgers which support the floor boards.

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To finalize this chapter, an example is shown of a free standing scaffold which was designed using SCIA Engineer [Ref.20]:

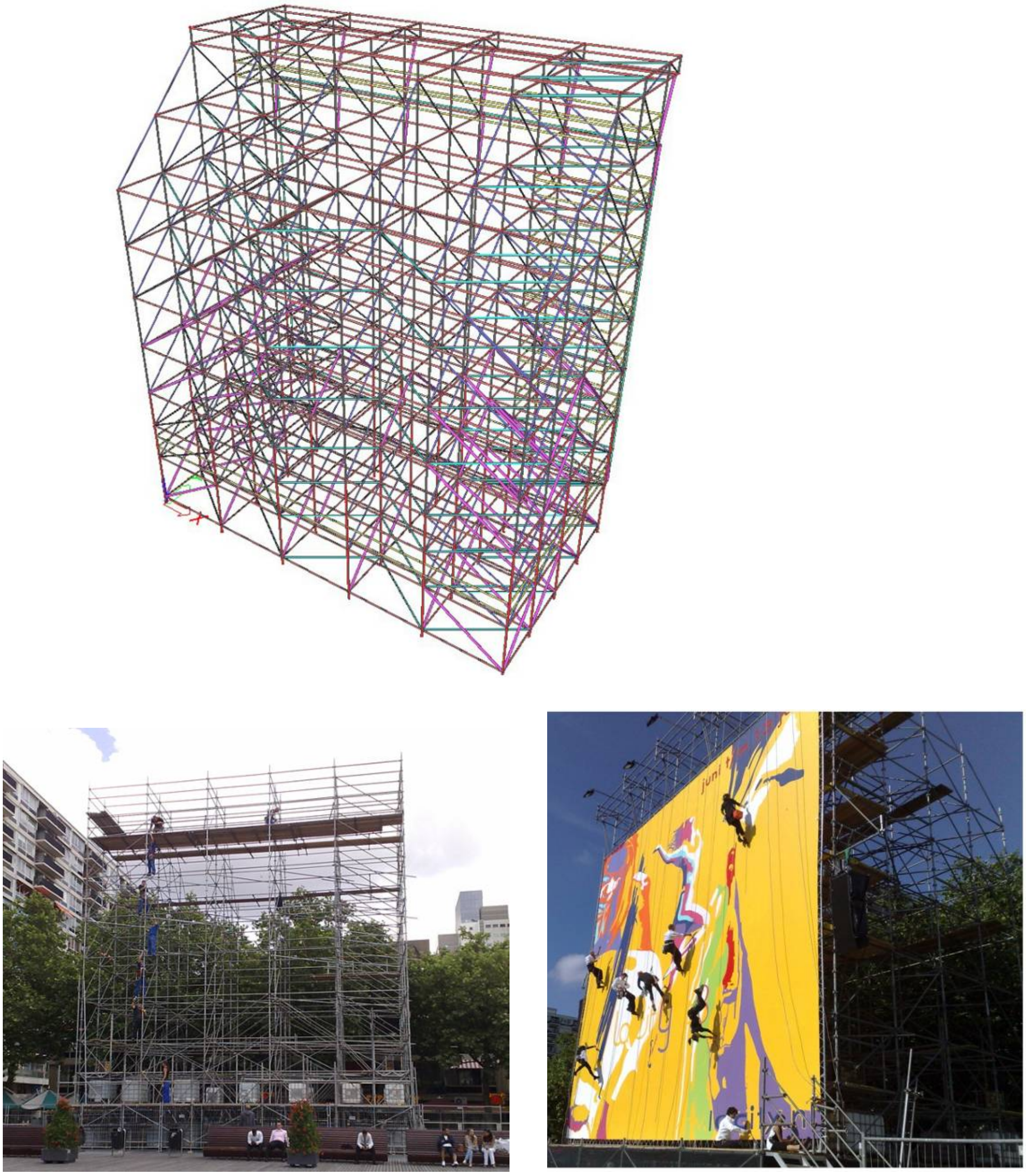

Figure 39: Example of a free standing scaffold modeled and analyzed with SCIA Engi neer

Thanks to the easy to use interface of SCIA Engineer, the modeling of this scaffold, including the application of the loading as well as the analysis was realized in only one working day. Afterwards, only half a day was spent to make modifications to the model after discussions with the City Council.

The current chapter provided an overview of how scaffolding structures are modeled and analyzed using SCIA Engineer. In the next chapter this method of design is verified using a real life test.

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4. Application and verification of the new analysis method

Following the recent design codes, the company SECU-BEL in Belgium used SCIAEngineer to perform an analysis of a typical scaffolding structure using the new design method and compared the results to an actual laboratory test [Ref.6].

The tests were executed in full accordance with the 'Full scale test' procedure as specified in the second chapter. The purpose of such a test is to verify the correctness of the analysis model. In case the results are in close comparison, the analysis model can then be applied safely for this type of system configuration.

The laboratory test was executed in France [Ref.7] using a 'frame type' scaffolding system of type Répamine.

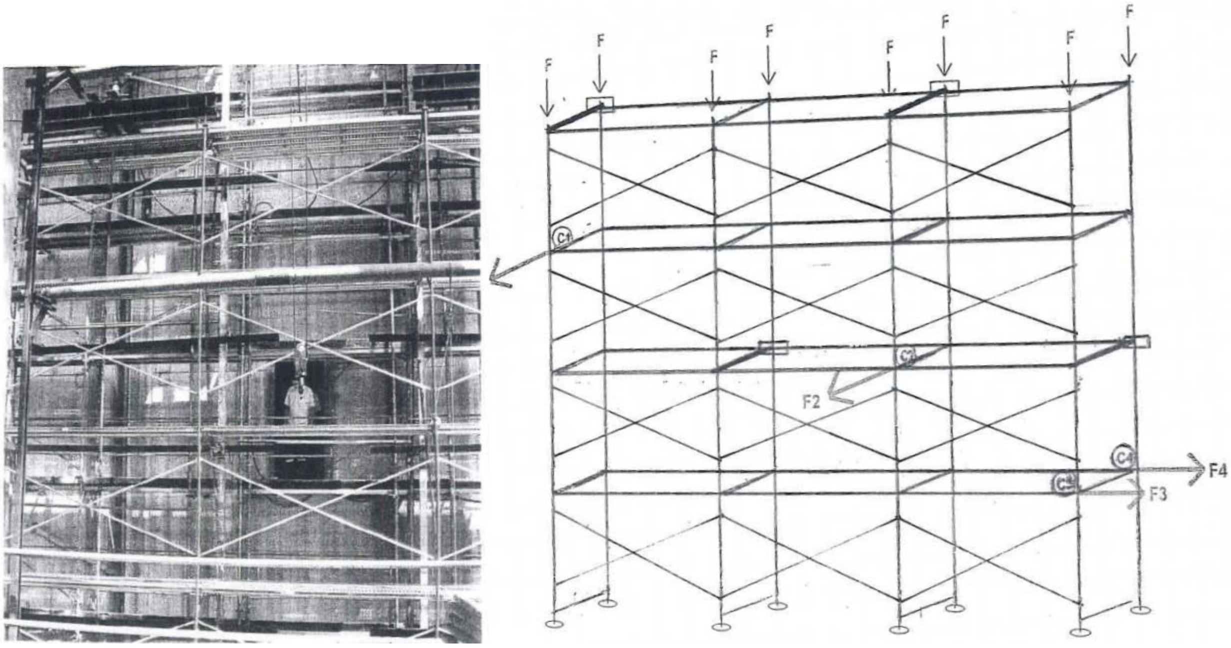

Figure 40: Picture and illustration of the test setup

Specifically for the scaffold system the tests consisted of the following parts:

- Determination of the stiffness parameters of the structure in the horizontal plane as prescribed in EN 12810-2 art.4.3 & Annex A2.

- Determination of the load-deformation behavior of the global structure as prescribed in EN 12810-2 art.4.4.2.

For the global behaviour, vertical loads were applied at the standards and horizontal loads at specific nodes perpendicular and parallel to the façade. The horizontal loading in this case represented effects caused by wind loading.

The tests resulted in a critical buckling load of **15.63 kN** for this specific system. [Ref.6]

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Using SCIA Engineer, an analysis model of the scaffold was made which included all required details in order to accurately predict the actual behaviour of the scaffold.

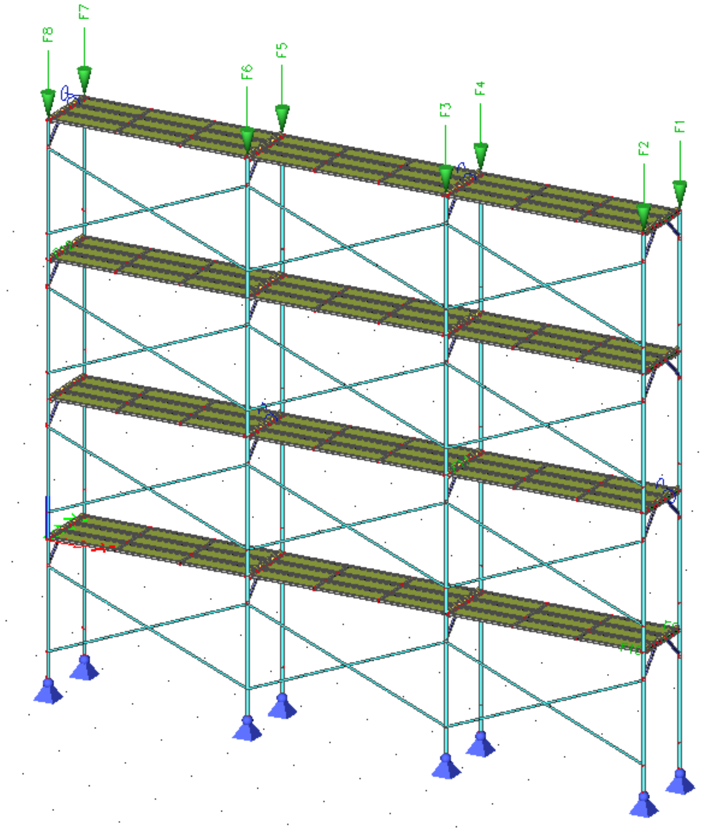
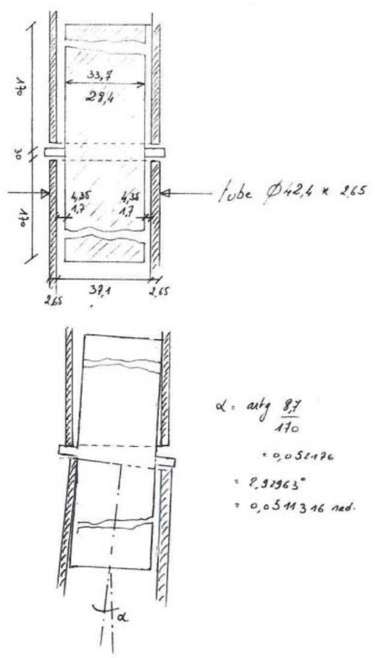


Figure 41: SCIA Engineer analysis model of the test setup

The SCIA Engineer analysis model included different coupler stiffness diagrams as prescribed by the codes.
Some of these non-linear characteristics are illustrated on the following pictures [Ref.9]:

a) The stiffness of the connections between the frames



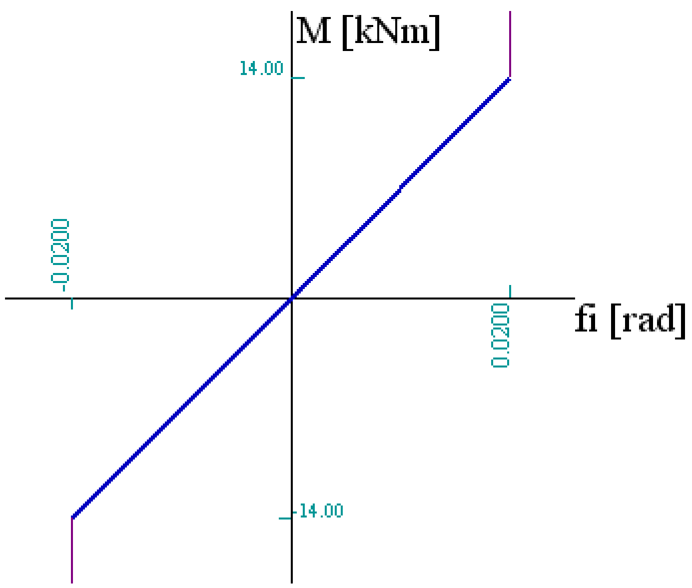


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Figure 42: Stiffness function of the connection between the frames

b) The stiffness and gap between the floor boards and the frames

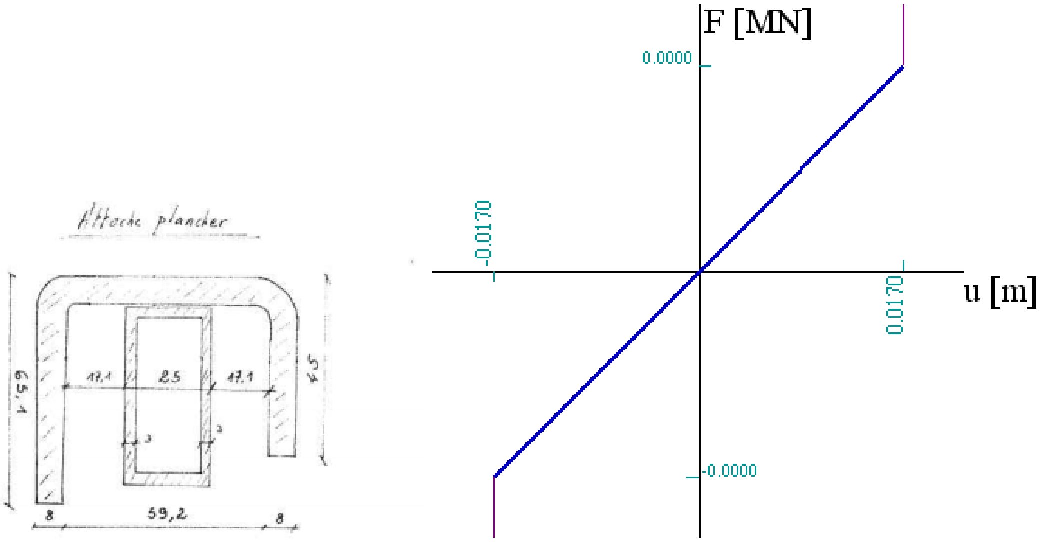

Figure 43: Stiffness function for the translation of the floor boards

As shown on the sketch, gaps can play an important role in the analysis: the floorboard can translate along its axis before actual contact is made with the frame. This translation however does not proceed without resistance: friction needs to be accounted for between the floorboard and the frame i.e. no displacement takes place without a dissipation of energy.

c) The elastic-plastic behaviour of the welded connections of the frames

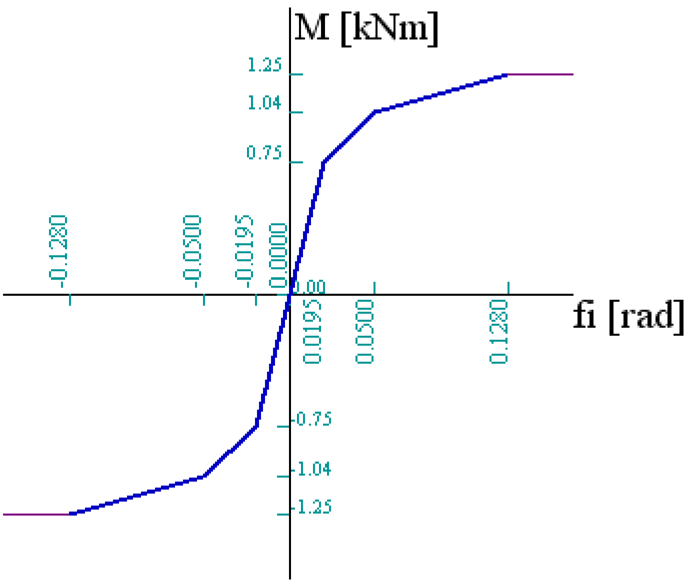

Figure 44: Moment-Rotation characteristic of the welded connections of the frames

In order to obtain this characteristic, tests were executed at the laboratory of the university in Liège, Belgium [Ref.9].

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The end result of a 2nd order analysis of this model [Ref.8] resulted in a critical buckling load of **15.50 kN**. When comparing this result to the laboratory test, the difference is shown to be less than **1%**!

This analysis showed that:

a) The recently published European Standards EN 12811 & 12810 provide accurate methods for design and testing of scaffolding systems.

b) Using SCIA Engineer the behaviour of a scaffold can be accurately modelled including all complex details.

Day by day people are using scaffolds; it is the responsibility of the engineer to make sure that the design of the scaffold provides a safe working environment for those people.

The current chapter showed that, using an analysis model as presented here attains this goal. The previous chapter illustrated how such a model is easily inputted within SCIA Engineer.

5. SCIA Scaffolding

The final part of this paper details the SCIA Scaffolding design methodology which uses a single intelligent model for all phases of the working process. The advantages of this approach compared to the existing working process are illustrated.

The existing workflow which is used in many scaffolding companies nowadays is illustrated on the following diagram [Ref.15]:

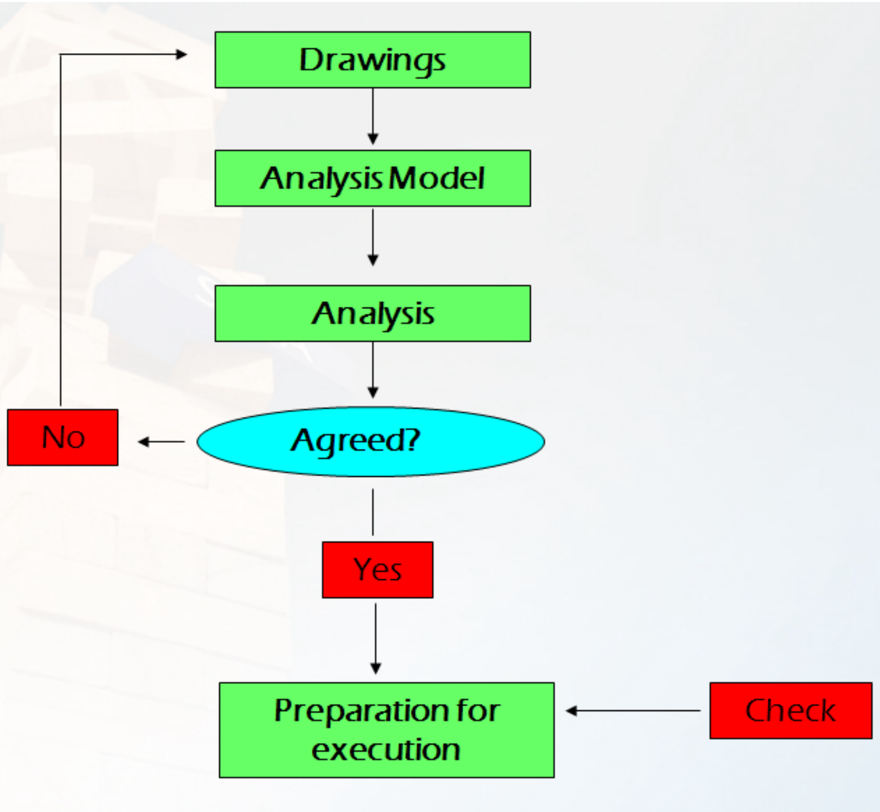

Figure 45: Existing Workflow diagram

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In a first step, 2D drawings and sketches are made which are required to illustrate the scaffolding concept to the client. In many cases, different views and sections are required which is time consuming.

When the order has been confirmed, the engineer starts to make an analysis model. This implies that the engineer has to again start from scratch i.e. the work which was already done to make the drawings has to be re-done to create the analysis model. In many cases 2D models are made using linear analysis which, as specified in the previous chapters, fails to provide a correct behaviour of the scaffold.

When the analysis is complete, the dimensions of the final scaffold are known and the preparation for the execution can start. Based on the drawings and analysis results, the required amount of material (standards, ledgers, couplers...) can be calculated. Again the same data has to be built up from the bottom since no intelligent model is available.

In the final stage, during execution, it occurs quite frequently that changes need to be made to the design. This implies that all elements of the above chain need to be re-done i.e. new drawings have to be made to incorporate the changes, the analysis model has to be adapted, an updated list of material components needs to be made etc. All these changes have to be done on several locations which again can lead to errors and takes up a lot of time.

To provide a solution to the above issues, Nemetschek Scia has developed the SCIA Scaffolding concept which is illustrated on the following diagram [Ref.15]:

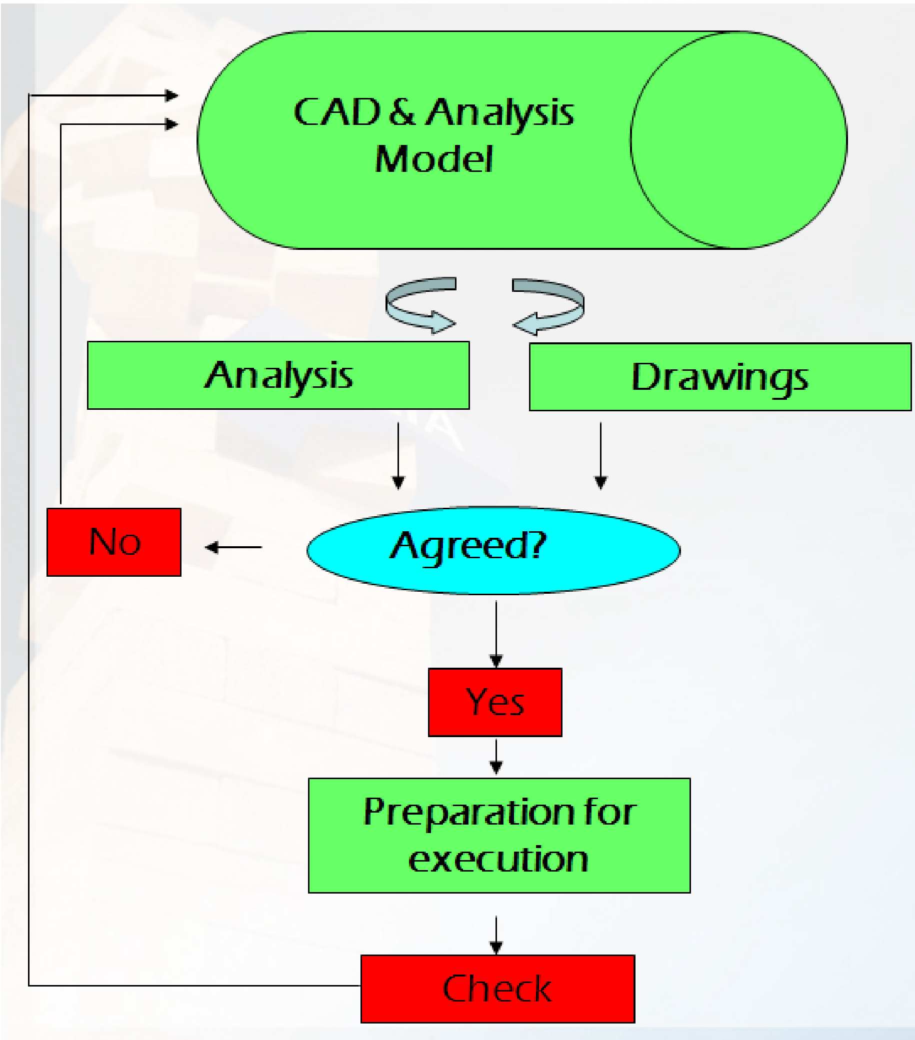

Figure 46: Scia Scaffolding workflow

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Using the modeller environment of SCIA Engineer, an intelligent 3D model of the scaffold is created in the first phase.

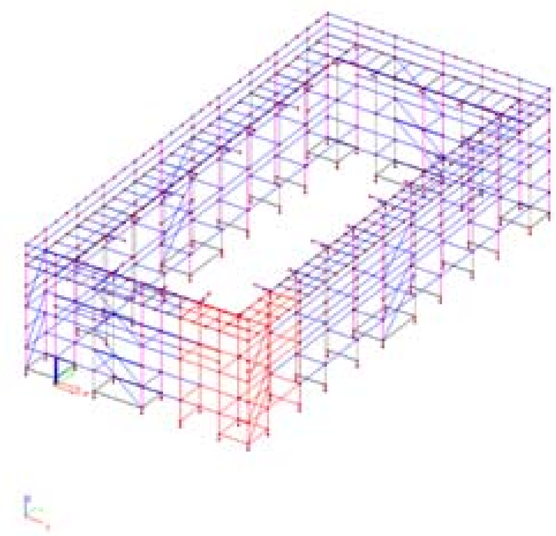

Figure 47: Intelligent 3D scaffolding model

From this 3D model, 2D drawings and sections are automatically generated.

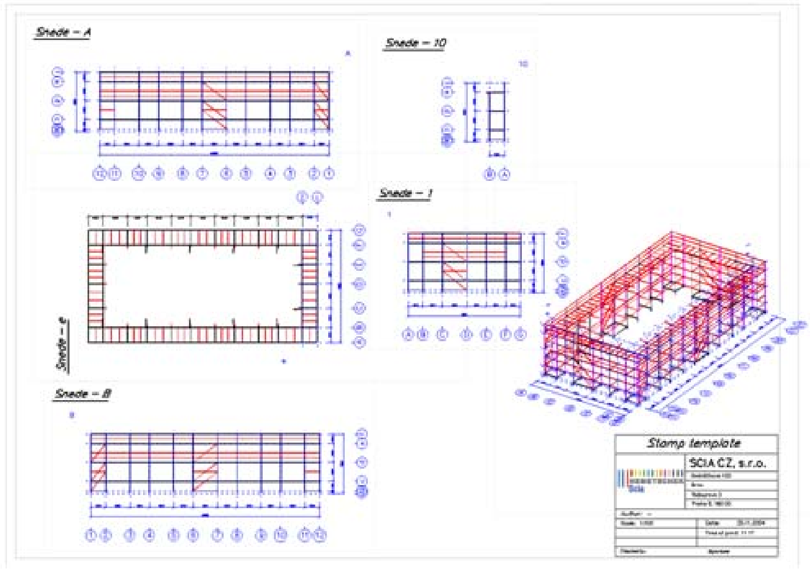

Figure 48: Automatic overview drawings derived from the 3D scaffolding model

The engineer then refines this model by adding loading, support conditions etc. Since the same model is used there is no loss in time, all previous data is directly available. The analysis within SCIA Engineer is then executed according to the design method of EN 12811. As outlined in the previous chapters this provides an accurate and exact model of the scaffolding structure.

When the analysis is complete, the same model is used to derive the Bill of Material required for the preparation of the execution. The amount of materials is directly extracted from the intelligent model which again saves time.

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CSS	Material	Unit mass [kg/m]	Length [m]	Mass [kg]	Surface [m^2]	Unit volume mass [kg/m^3]	Volume [mm^3]
Standard - RO48.3X3.2	S 235	3,6	77,000	273,8	11,930	7850,0	3,4881e+07
Ledger - RO48.3X3.2	S 235	3,6	99,590	354,1	15,430	7850,0	4,5114e+07
Guardrail - RO48.3X3.2	S 235	3,6	75,180	267,3	11,648	7850,0	3,4057e+07
Bracing - RO48.3X2.3	S 235	2,6	22,301	58,1	3,435	7850,0	7,4041e+06
Floor 0,32 - RECT (40; 320)	Floor 0,32	8,2	93,150	763,8	67,068	640,6	1,1923e+09
Toeboard - RECT (150; 20)	Toeboard	2,3	37,590	87,2	12,781	773,3	1,1277e+08
Tube - RO48.3X3.2	S 235	3,6	5,270	18,7	0,816	7850,0	2,3873e+06
GT Chord - RO48.3X3.2	S 235	3,6	20,000	71,1	3,099	7850,0	9,0600e+06
GT Diagonal - SHSCF25/25/2.5	S 235	1,6	18,420	30,2	1,769	7850,0	3,8498e+06

Figure 49: Bill of Material derived from the 3D scaffolding model

SCIA Engineer allows the user to export the Bill of Material to different file formats, including MS Excel ©. Using this approach, it is possible to further elaborate the Bill of Material to include quantities, additional elements etc.

This is illustrated on the following picture which shows the Bill of Material within SCIA Engineer which is then exported to MS Excel © and expanded with quantities.

Bill of material

Name	Mass [kg]	Surface [m^2]	Volume [mm^3]
Total results :	354,1	15,430	4,5114e+07

CSS	Material	Unit mass [kg/m]	Length [m]	Mass [kg]	Surface [m^2]	Unit volume mass [kg/m^3]	Volume [mm^3]
Ledger 1.09 - RO48.3X3.2	S 235	3,6	25,070	89,2	3,884	7850,0	1,1357e+07
Ledger 2.07 - RO48.3X3.2	S 235	3,6	74,520	265,0	11,545	7850,0	3,3758e+07

	A	B	C	D	E	F	G	H	I
1	Bill of material								
2	CSS	Material	Unit mass	Length	Mass	Surface	Unit volume mass	Volume	Quantities
3			[kg/m]	[m]	[kg]	[m 2]	[kg/m 3]	[mm 3]	#
4	Ledger 1.09 - RO48.3X3.2	S 235	3,6	25,07	89,2	3,884	7850	1,14E+07	23
5	Ledger 2.07 - RO48.3X3.2	S 235	3,6	74,52	265	11,545	7850	3,38E+07	36

Figure 50: Export of Bill of Material into MS Excel © and expanded with quantities

Another big advantage is seen in the final stage: in case changes are required they only have to be made on one position! A change in the model directly leads to an updated analysis, updated drawings and an updated bill of material.

It is obvious that this design methodology provides a clear advantage in time and costs compared to the existing workflow.

Currently the Bill of Material is based on the member lengths within the analysis model i.e. from node to node. The vision of Nemetschek Scia aims at further improving the SCIA Scaffolding functionality to include article numbers of different manufacturers in order to provide an exact Bill of Material.

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6. Summary

In the first part of this paper an overview has been given on the recently published design method for scaffolds as outlined in the European Standards EN 12811 & 12810. This method stresses the use of 2nd order analysis to accurately analyze scaffolding structures.

A separate chapter was devoted to illustrate the modelling and analysis of scaffolding structures within SCIA Engineer.

The two previous chapters were then combined by comparing the results of a SCIA Engineer analysis model to a real life laboratory test. The comparison showed a close agreement with a deviation of less than 1%.

The final part of this paper detailed the SCIA Scaffolding design methodology which uses a single intelligent model for all phases of the working process. The advantages of this method compared to the existing workflow were illustrated.

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7. References

[1] EN 12810-1: *Façade scaffolds made of prefabricated elements – Part 1: Product specifications*, CEN, 2004.

[2] EN 12810-2: *Façade scaffolds made of prefabricated elements – Part 2: Particular methods of structural design*, CEN, 2004.

[3] EN 12811-1: *Temporary works equipment – Part 1: Scaffolds – Performance requirements and general design*, CEN, 2003.

[4] EN 12811-2: *Temporary works equipment – Part 2: Information on materials*, CEN, 2004.

[5] EN 12811-3: *Temporary works equipment – Part 3: Load Testing*, CEN, 2003.

[6] Strimelle, C., SECU-BEL, *Répamine, Etablissement des capacités portantes de l'échafaudage type V22*, 2007.

[7] Strimelle, C., SECU-BEL, *Répamine, Etablissement des capacités portantes de l'échafaudage Annexe 1*, 2007.

[8] Strimelle, C., SECU-BEL, *Répamine, Etablissement des capacités portantes de l'échafaudage Annexe 2*, 2007.

[9] Strimelle, C., SECU-BEL, *Répamine, Etablissement des capacités portantes de l'échafaudage Annexe 3*, 2007.

[10] Nather F., Lindner J., Hertle R., *Handbuch des Gerüstbaus*, Ernst & Sohn, 2005.

[11] Chan S.L., Chu A.Y.T, Albermani F.G., *Stability and simulation-based design of steel scaffolding without using the effective length method*, International Journal of Structural Stability and Dynamics Vol. 3 No. 4 pp443-460, 2003.

[12] Layher, *Allround Scaffolding*, Technical Brochure, 2008.

[13] Ratay R.T., *Forensic Structural Engineering Handbook*, Mcgraw-Hill, 2000.

[14] van Santen R.J., Straatsma H., Vogelaar W.L., *Steigerongeval Amercentrale*, Ministerie van Sociale Zaken en Werkgelegenheid, 2007.

[15] Vanmechelen R., *Scia Scaffolding seminarie*, Nemetschek Scia, 2008.

[16] Greiner R., *Stabilitätsnachweis von Stabwerken nach dem Eurocode – neue Möglichkeiten*, Stahlbau Seminar Biberach, 2005.

[17] EN 1993-1-1: *Eurocode 3: Design of steel structures - Part 1-1: General rules and rules for buildings*, CEN, 2005.

[18] DIN 4420 Teil 1: *Arbeits- und Schutzgerüste, Allgemeine Regelungen Sicherheitstechnische Anforderungen, Prüfungen*, Beuth Verlag 1990.

[19] *Werksteiger rond bovenstructuur baskuulbrug te Zeebrugge*, Travhydro, 2006.

[20] *Vrijstaande steiger Schouwburgplein Rotterdam*, Travhydro, 2008.

[21] *Répamine, Ferronnerie et outillage pour la Construction,* www.repamine.be

[22] *Zulassung Z-8.22-869 Modulsystem Ringscaff,* Deutsches Institut für Bautechnik*, 2005.*

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